# APPENDIX 5

## EVALUATING EVAPORATION ESTIMATES FOR IID

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by
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## INTRODUCTION

Disk file copies (UPDATE.DBF and UPDATE1.DBF) of CIMIS data used
in preparing the summary data in the Boyle/Styles (1993) report
were used in this study as was done for reference ET estimates.
The purpose of evaporation estimates is to evaluate various
equations for estimating evaporation for use in water balance
estimates for the Imperial Irrigation District and the Coachella
Valley Water District.

## PROCEDURES

The main changes in net radiation estimates for water surfaces is
the difference in albedo between water surfaces and reference
crop and the temperature of the evaporating surface.

### Mean Daily Albedo

Mean daily albedo also changes with solar declination or zenith
angle.  The major difference in net radiation estimates for water
v. a reference vegetated is the change in albedo.  The USGS
developed a table of water albedo values v. cloud cover and
height.  Using limited albedo data available in the USGS Salton
Sea study, I developed a functional relationship for water
surface albedo. The resulting equation is in Appendix A.

### Measurements and Estimates of Salton Sea Evaporation

Monthly and mean annual evaporation values presented by Hely et
al. (1966) were used as a reference for evaluating various
equations for estimating evaporation.

### Equations and Methods Used

The equations and procedures used are summarized in Appendix A.

## RESULTS OF ANALYSES

### Evaporation From Salton Sea and Fresh Water

Monthly evaporation estimates made by the USGS using three
methods, water budget, energy budget and mass transfer, and
measurements of variables in 1961-1962 are summarized in Fig. 1
(also see Appendix B).  The average evaporation was 71.8 inches
for the period.  When adjusted for salinity (E x 1.02), the
average evaporation from fresh water for 1961-62 was **73.2 inches.**

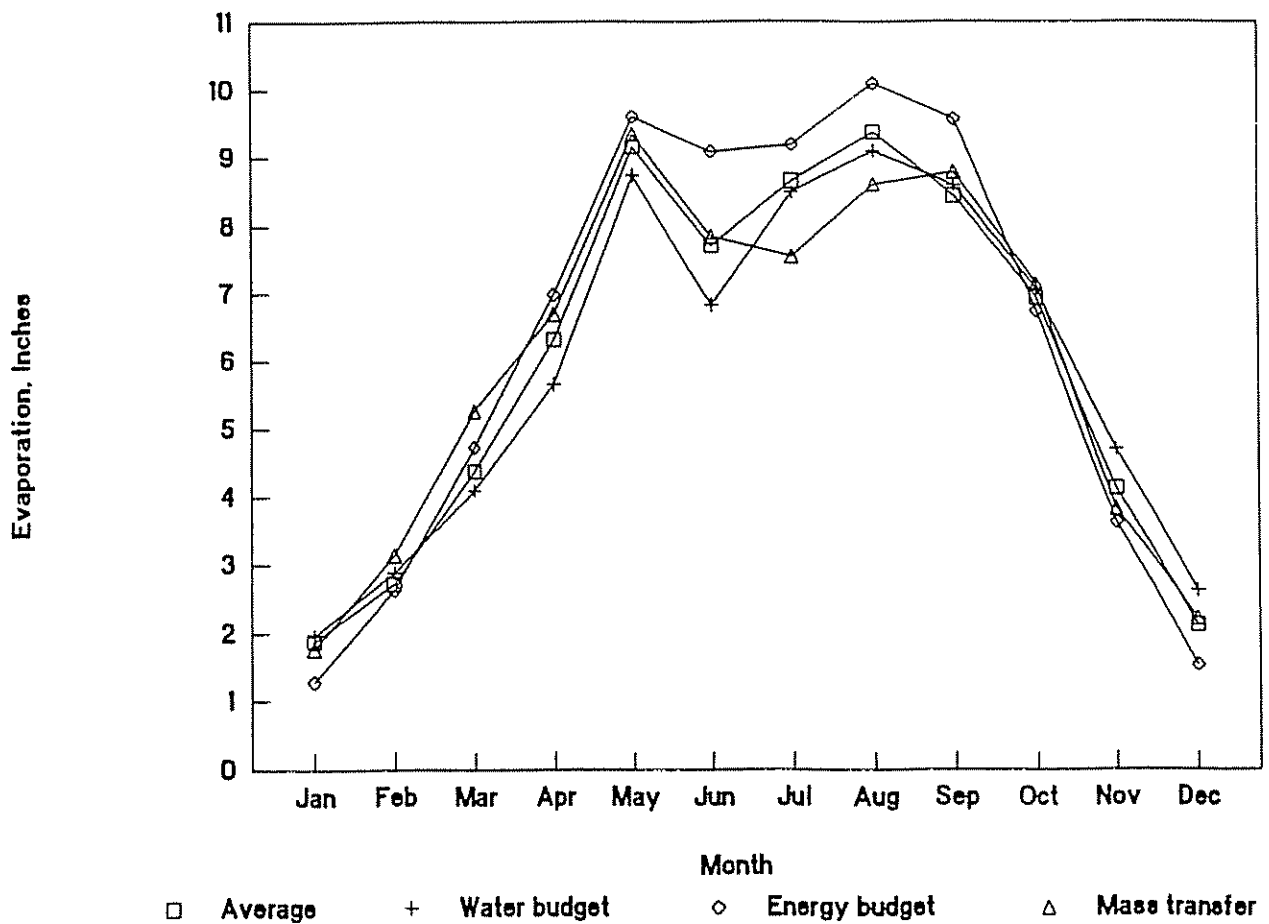# MONTHLY EVAPORATION - USGS
## Salton Sea, California

Figure 1. Estimated monthly evaporation from fresh water based on
evaporation from the Salton Sea in 1961 and 1962 (From
Hely et al., 1966).

The average evaporation for the 1948-1962 period was 69 inches which was considered to be the normal rate. When adjusted for salinity, the normal average is **70.4 inches**.

### Estimates of Annual Fresh Water Evaporation Using CIMIS Data

Estimates of annual evaporation from fresh water reservoirs for three CIMIS sites in the IID are shown in Fig. 2-4. The methods compared are: 1) USGS 1961-62 average x 1.02; CIMIS $ET_0$; 2) Penman-Monteith evaporation with $z_0 = 0.0002$ m, $r_c = 0$, and using mean air temperature to compute the vapor pressure deficit; 3) Penman $E_0$ arbitrarily reduced by 0.9 (Penman EO x 0.9); and 4) Priestley-Taylor (P-T) potential evaporation.

### Estimates of Monthly Fresh Water Reservoir Evaporation

Average monthly evaporation estimates for CIMIS Stations 41, 68 and 87 are compared with USGS monthly values in Fig. 5. The lag in the USGS values in the spring and the higher monthly values in the fall are typical of lakes where heat storage is involved. A tabluar summary of these values is presented in Appendix B.

### Estimates of Mean Monthly Flowing Fresh Water Evaporation

Because the surface of flowing water is not as smooth as reservoir surfaces, the roughness parameter in the P-M equation was increased from 0.0002 m to 0.001 m. The P-M equation is sensitive to changes in the roughness parameter when it is very small. Wieringa (1992) suggested a value of $z_0 = 0.005$ for a smooth surface (Featureless land surface without any noticeable obstacles and with negligible vegetation, i.e., ... or fallow open country.) A value of 0.015 m was used for reference ET estimates. Penman $E_0$ values were used without adjustment. A tabular summary of these values is presented in Appendix B.

### Summary of Annual Fresh Water Evaporation Estimates

A summary of fresh water reservoir and flowing water annual evaporation estimates is presented in Table 1. Average CIMIS $ET_0$ values were about equal to average estimated evaporation from reservoirs, but were about 87 percent of estimated evaporation from flowing fresh water.

# EVAPORATION ESTIMATES – CIMIS 41
## Mulberry Site



Figure 2. Comparison of mean annual evaporation for CIMIS Station 41 computed with the Penman-Monteith, Penman (1963) $E_o$ and Priestley-Taylor equations with CIMIS $ET_o$ values.

Figure 3. Comparison of mean annual evaporation for CIMIS Station
68 computed with the Penman-Monteith, Penman (1963) $E_o$
and Priestley-Taylor equations with CIMIS $ET_o$ values.

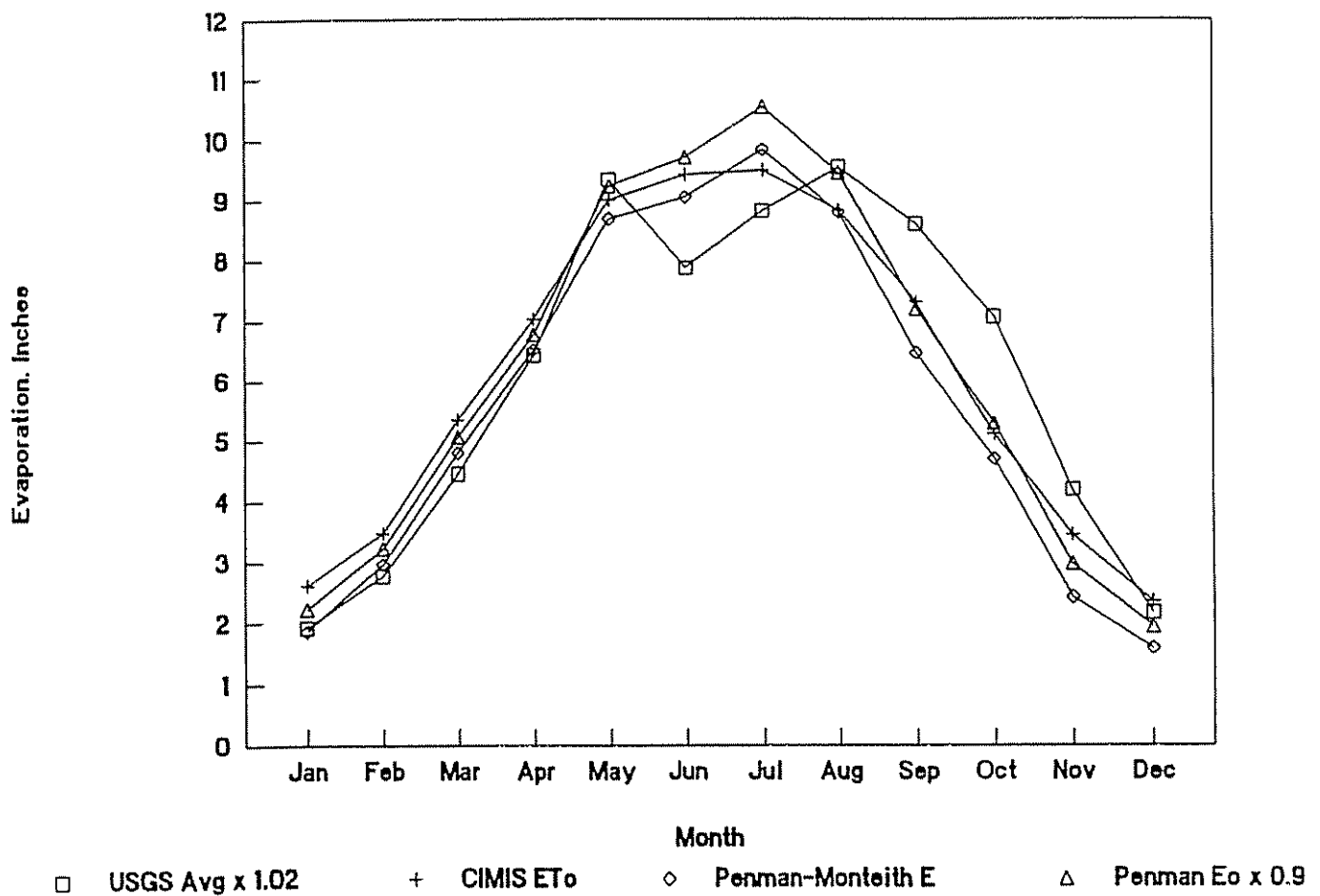# EVAPORATION ESTIMATES – CIMIS 87
## Meloland Site

Figure 4. Comparison of mean annual evaporation for CIMIS Station
87 computed with the Penman-Monteith, Penman (1963) $E_o$
and Priestley-Taylor equations with CIMIS $ET_o$ values.

# EVAPORATION ESTIMATES – IMPERIAL VALLEY
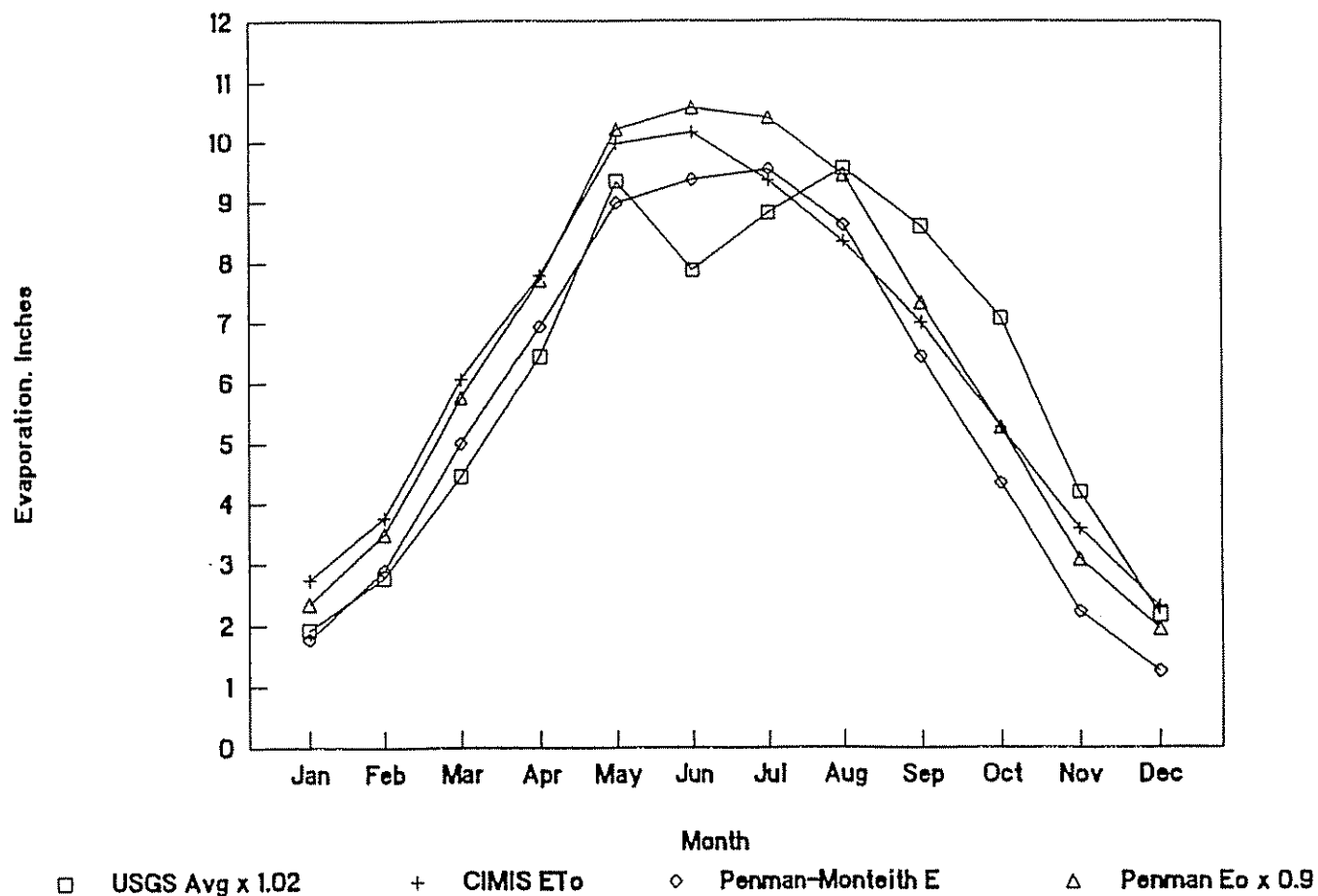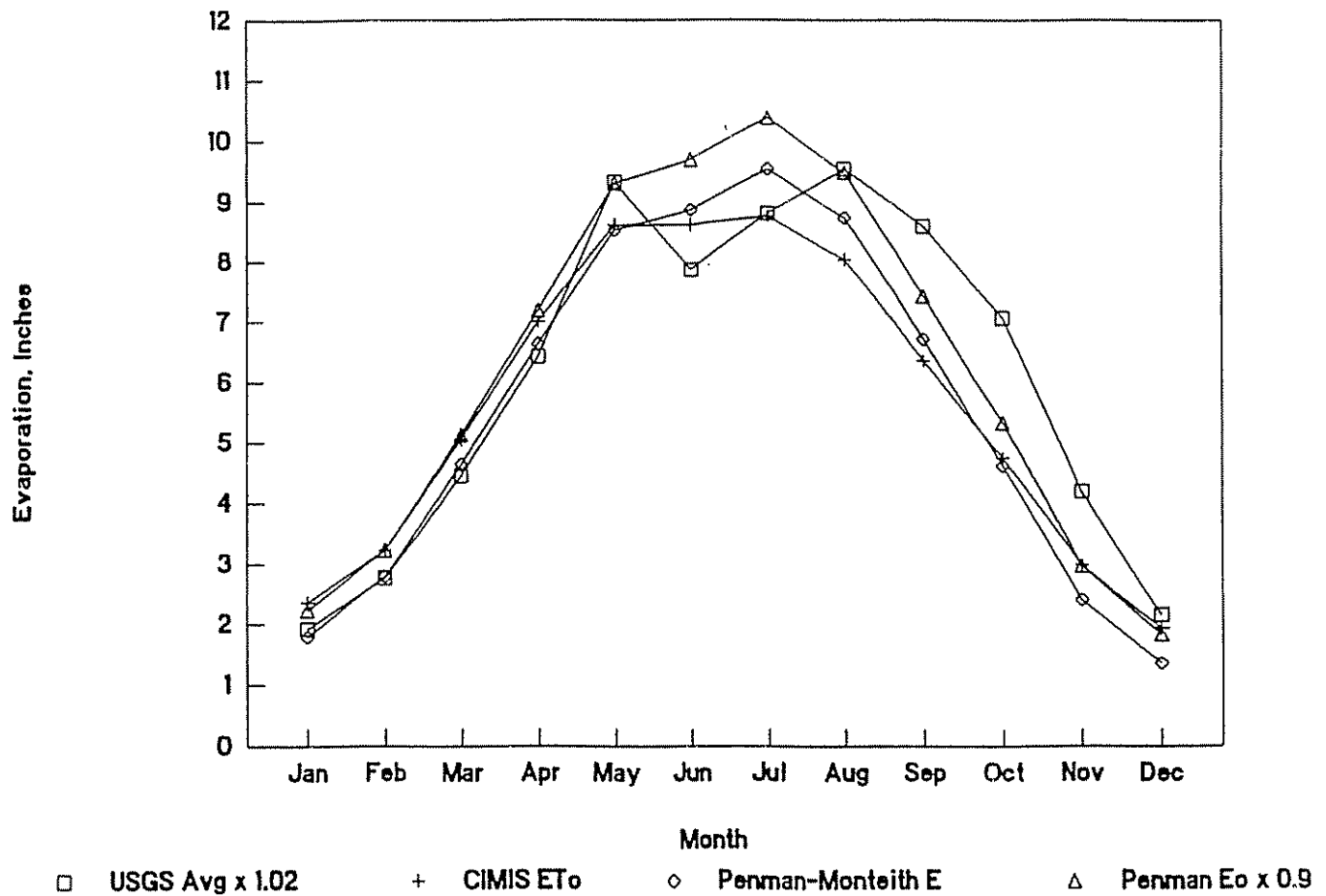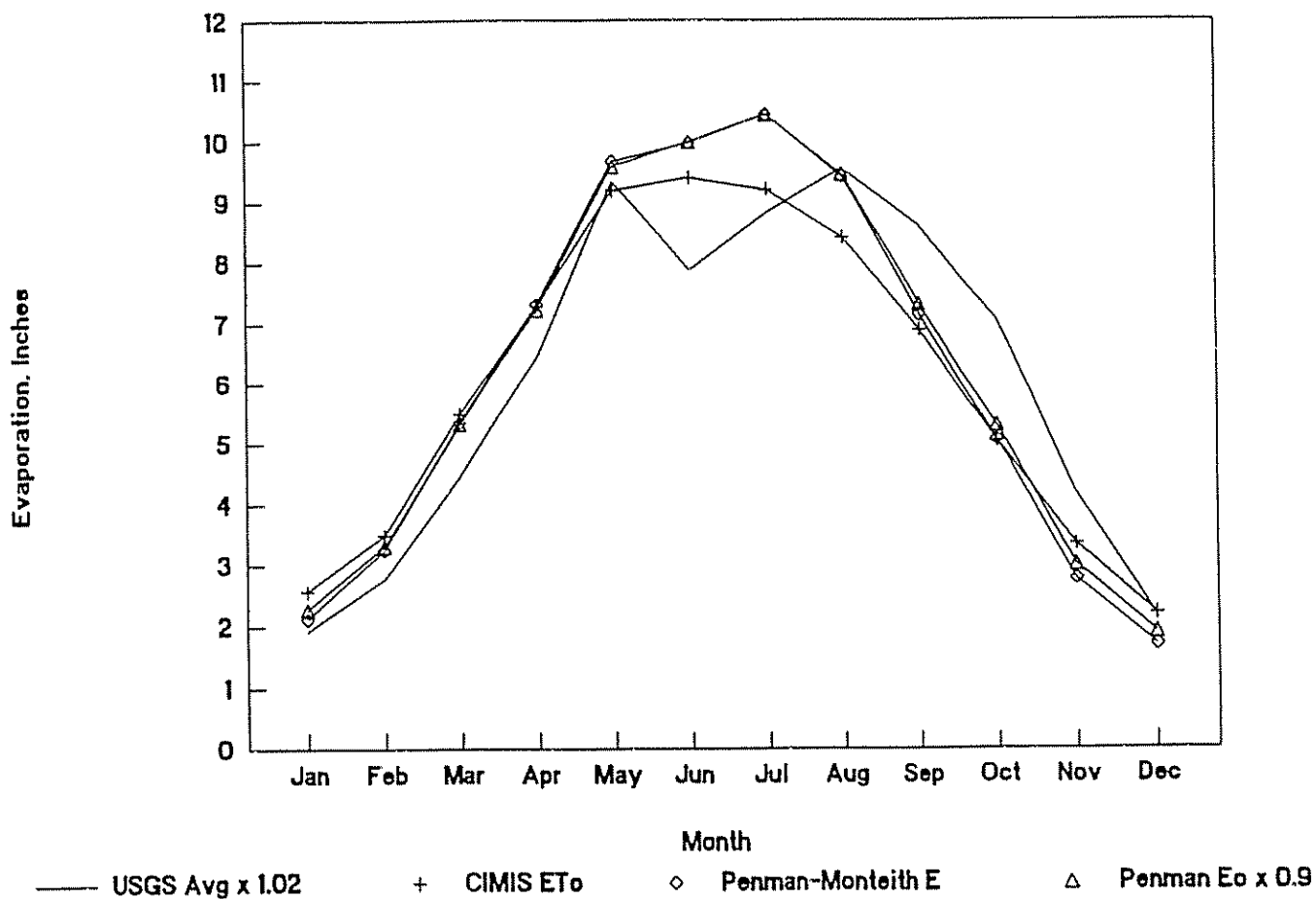
## CIMIS Sites 41, 68 & 87



Figure 5. Comparison of mean monthly reference ET for CIMIS Stations 41, 68 and 87 computed with the Penman-Monteith and Penman (1963) equations with CIMIS values and USGS 1961-62 values.

Table 1. Summary of estimated annual evaporation from reservoirs and canals/rivers in the IID.

| Period | Station 41 Inches | Station 41 Percent | Station 68 Inches | Station 68 Percent | Station 87 Inches | Station 87 Percent | Average Inches |
|---|---|---|---|---|---|---|---|
| Annual fresh water reservoir evaporation, inches | | | | | | | |
| All years: | | | | | | | |
| CIMIS ET$_o$ | 73.6 | | 76.3 | | 67.8 | | 72.6 |
| P-M | 75.9 | | 74.5 | | 72.5 | | 74.3 |
| P E$_o$ x 0.9 | 73.7 | | 77.6 | | 74.3 | | 75.2 |
| P-T | 67.1 | | 69.0 | | 71.1 | | 69.1 |
| Average | 72.5 | 99.6 | 74.3 | 102.1 | 71.4 | 98.1 | 72.8 |
| Annual fresh water evaporation from canals and rivers, inches | | | | | | | |
| All years: | | | | | | | |
| P-M | 86.4 | | 83.7 | | 80.0 | | 83.4 |
| Pen E$_o$ | 81.2 | | 86.2 | | 82.6 | | 83.6 |
| Average | 83.8 | 100.5 | 85.5 | 102.5 | 81.3 | 97.5 | 83.4 |

## Simplified Estimates of Reservoir Evaporation

A regression analysis of P-M estimates of daily monthly fresh water evaporation v. $R_s$ x $T_{avg}$ is shown in Fig. 6. Simplified estimates of mean daily monthly fresh water evaporation can be made using the following equation derived for CIMIS Site 41.

$$E = 0.76 + 0.0097 (R_s Tavg), \quad mm/day \qquad (1a)$$

where E is evaporation, mm/day, $R_s$ = solar radiation in MJ/(m$^2$ day), and $T_{avg}$ = average daily temperature in degrees C. The R-squared value for this regression was 0.969. The same equation for E in in/day, solar radiation in ly/day and temperature in degrees F is:

$$E = 0.03 + \frac{0.89}{10^5} [R_s (T_{avg} - 32)], \quad inch/d \qquad (1b)$$

If monthly evaporation estimates are needed for the study period, regressions for both reservoir and flowing water evaporation involving all three locations can be developed.

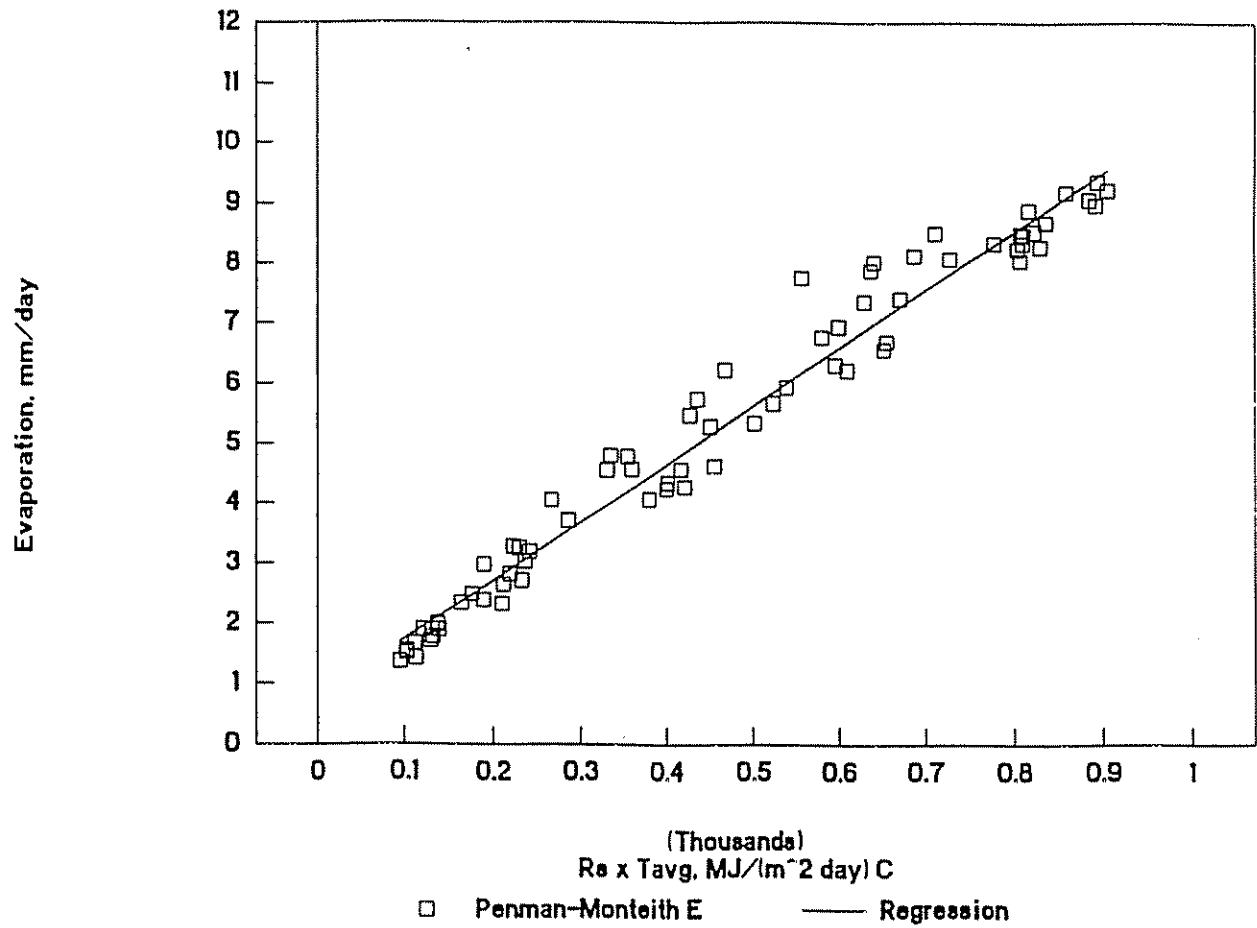# EVAPORATION ESTIMATES - CIMIS 41

Mulberry Site



Figure 6. Estimated mean daily monthly evaporation v. the product of solar radiation and mean monthly air temperature.

## SUMMARY AND CONCLUSIONS

A spreadsheet program was developed to estimate mean monthly evaporation from IID fresh water reservoirs and flowing fresh water. The Priestley-Taylor estimates of reservoir evaporation for data from three IID CIMIS sites was essentially equal to the adjusted normal evaporation from the Salton Sea. The estimated mean annual fresh water evaporation from reservoirs in the IID was 73 inches. The estimated mean annual evaporation from flowing fresh water evaporation using the Penman-Monteith and Penman (1963) combination equations was 83 inches.

Mean monthly evaporation from fresh water reservoirs and flowing canals and rivers can be made using a simple linear equation with the main variable being the product solar radiation and mean air temperature.

## REFERENCES

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**Culf, A.D., and J.H. Gash.** 1993. Longwave radiation from clear skies in Niger: A comparison of observations with simple formulas. Am. Meteorol. Soc. 32:539-547.

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# APPENDIX A5-A

## EQUATIONS USED TO ESTIMATE EVAPORATION

### Net Radiation

A slight modification of the net radiation equation used for reference ET was made for evaporation to enable using recent calibrated equation for downward long-wave radiation and a water surface temperature for upward long-wave radiation.

$$R_n = (1 - \alpha) R_s + R_{ld} - R_{lu} \tag{A-1}$$

where $R_n$ is net radiation, MJ/(m$^2$ day), $\alpha$ = albedo, $R_{ld}$ = downward long-wave radiation, and $R_{lu}$ = upward long-wave radiation, MJ/(m$^2$ day).

### Net Long-Wave Radiation

Net long-wave radiation was calculated the same as for reference ET estimates except for separating downward and upward long-wave radiation.

$$R_b = \left( a \frac{R_s}{R_{so}} + b \right) (R_{ld} - R_{lu}) \tag{A-2}$$

where $(R_{ld} - R_{lu}) = R_{bo}$ is net long-wave radiation on a clear day, MJ/(m$^2$ day), $R_s$ = measured solar radiation, and $R_{so}$ = clear-day solar radiation. Adjustments for cloud cover was the same as used for reference ET, a = 1.126 and b = -0.07 (Wright, Manual 70, p. 137).

Downward long-wave radiation was calculated using a recent calibration of Brutsaert's atmospheric emissivity equation (Brutaert, 1982). Culf and Gash (1993) calibrated Brutsaert's original equation for dry climate replacing the constant 1.24 with 1.31, i.e., $\epsilon_a = 1.31(10\ e_d/T_{kavg})^{1/7}$. The USGS estimated the reflectance of long-wave radiation, r, from water surfaces to be 0.03 based on measurement made during the 1961-1962 Salton Sea study (Hely et al., 1966)

$$R_{ld} = (1 - r)\, 1.31 \frac{4.90\, T_{kavg}^4}{10^9} \left( \frac{10\, e_d}{T_{kavg}} \right)^{1/7} \tag{A-3}$$

where $e_d$ is saturation vapor pressure at dewpoint temperature, r = the reflected long-wave radiation from water, $T_{kavg}$ is the

average absolute temperature (K), and the Stefan-Boltzmann constant is $\sigma = 4.903/10^9$ MJ/(m$^2$ day).

Upward long-wave radiation was calculated using the emissivity for water surface, $\epsilon_w = 0.97$ and the water temperature.

$$R_{lu} = \epsilon_w \frac{4.90}{10^9} (T_{ko}^4) \qquad\qquad (A-4)$$

Mean air temperature was assumed for water surface temperature since Hely et al. (1966) reported that the temperature of shallow streams in the area differed only slightly from mean air temperature.

### Albedo

The major difference in net radiation estimates for water v. a reference vegetated is the change in albedo. During the Lake Hefner studies in the 1950s, the USGS developed a table of water albedo values v. cloud cover and height. In the 1961-62 study, the USGS used these values, but reported only a few example values of reflected solar radiation for periods during the year based on the tabular values. Using these limited data, I developed a functional relationship for water surface albedo. A comparison of the following equation with reported values is shown in Fig. A-1.

$$\alpha_w = 0.060 + 0.021[1 - \cos(\frac{2\pi CD}{365} - 2.9)] \qquad\qquad (A-5)$$

where $\alpha_w$ is albedo for the water surface and CD = calendar day (1-365).

### Clear-Day Solar Radiation

Clear-day solar radiation was based on the same relationship used for the reference ET estimates.

$$R_{so} = R_a [0.725 + 0.025\cos(\frac{2\pi CD}{365} - 2.6)] \qquad\qquad (A-6)$$

where $R_{so}$ is clear-day solar radiation, $R_a$ = extraterrestrial solar radiation and CD = the calendar day. Although the constant of the cosine function is 2.6, a value of 2.9 would shift the values to coincide more closely with the longest day of the year.

# ESTIMATED ALBEDO

Water Surfaces – IID

Albedo

0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0

1   22   74   105   166   204   258   316   349

15   46   99   135   196   227   288   319   365
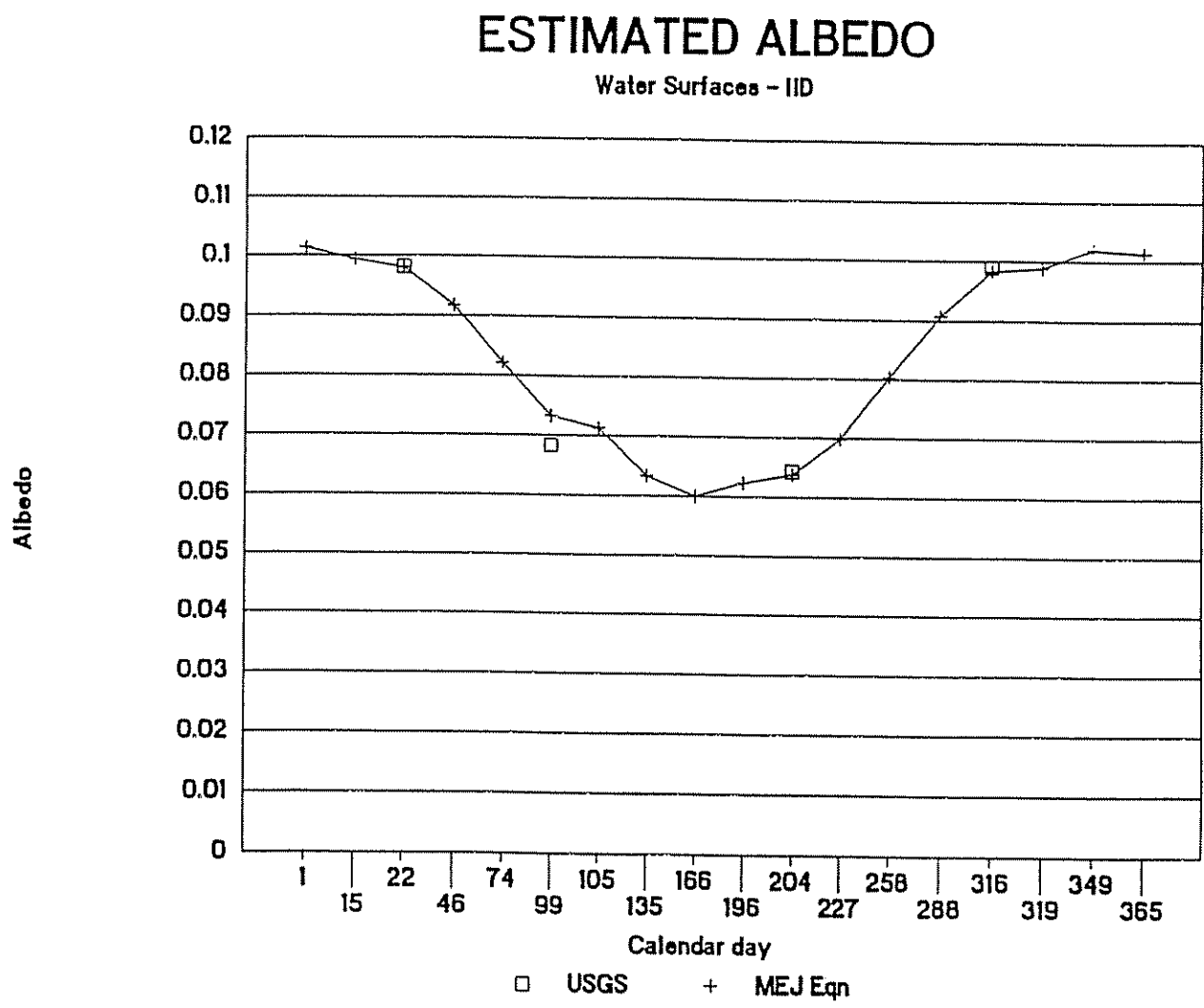
Calendar day

□ USGS   + MEJ Eqn

Fig. A-1. Monthly albedo values reported by the USGS v. the
values used to estimate net radiation.

A5-A3

Eq. A-6 was based on observed high values of solar radiation from CIMIS data and calculated daily $R_a$ values. The range in atmospheric transmissibility ranges from 0.69 in December-January to 0.75 in June-July. FAO uses a constant of 0.75 for $R_{so}/R_a$ (Smith, 1991).

### Penman (1963) Equation for Pan Evaporation

The change in albedo is the main difference in Penman evaporation estimates, $E_o$. Penman suggested a minor change in the wind function for the following equation for evaporation based on Lake Hefner studies:

$$\lambda E_o = \frac{\Delta}{\Delta + \gamma} (R_n - G) + \frac{\gamma}{\Delta + \gamma} 6.43 W_f (e_o - e_d) \qquad (A-7)$$

where $\lambda ET_o$ is the latent heat energy in MJ/(m$^2$ day), $\lambda$ = the latent heat of vaporization at mean air temperature, $\Delta$ = the slope of the saturation vapor pressure-temperature curve at mean air temperature, $\gamma$ = the psychrometric constant that is a function of the specific heat of moist air, atmospheric pressure and latent heat of vaporization, $R_n$ = net radiation, G = soil heat flux, $W_f = 0.5 + 0.536 u_2$, where $u_2$ = mean daily wind speed in m/s, $e_o$ = saturation vapor pressure of the water surface which was assumed to be at mean air temperature, and $e_d$ = saturation vapor pressure at dewpoint temperature. G, which would be very small for monthly estimates, was assumed to be zero. Equation 7.13 in Manual 70 was used for $\Delta$, 7.15 for $\gamma$, and a slight modification of Eq. 7.11 was used for $e_o$ and $e_d$ (Smith, 1991). $E_o$ in depth units is obtained by dividing by the latent heat of vaporization per unit depth.

### Penman-Monteith Equation

The Penman-Monteith equation is the same for both water surfaces and vegetated surfaces except the atmospheric resistance term, $r_a$, changes because of the surface rougness and canopy resistance, $r_c$, which was set at "0" for water. In addition, I based the vapor pressure deficit on the saturation pressure based on average temperature and dewpoint temperature instead of using the mean of the deficit based on maximum and minimum temperatures.

$$\lambda E = \frac{\Delta}{\Delta + \gamma*} (R_n - G) + \frac{\lambda}{\Delta + \gamma*} \rho \frac{0.622\lambda}{P} 86,400 \frac{(e_o - e_d)}{r_a} \qquad (A-8)$$

where $\rho$ = the density of moist air, kg/m$^3$, P = atmospheric pressure, kPa, $\gamma* = \gamma(1 + r_c/r_a)$, $r_c$ = canopy resistance, and $r_a$ =

aerodynamic resistance in s/m. The other variables are the same as in Penman's equation. Therefore, since the canopy resistance is "zero" for water, the radiation term is identical to that in the Penman equation (Penman, 1966).

The aerodynamic resistance is based on the heights of air temperature, humidity and wind speed measurements and surface rougnesss as follows (Allen et al., 1989):

$$r_a = \frac{\left[\ln\left(\frac{z_m - d}{z_{om}}\right)\right]\left[\left(\frac{z_h - d}{z_{oh}}\right)\right]}{k^2 u_z} \qquad (A-9)$$

where $r_a$ has units of s/m, $z_m$ is the height of wind measurement, $z_h$ is the height of air temperature and humidity measurements, d is the zero displacement height above the surface, $z_{om}$ is the roughness length parameter for momentum transfer (m), and $z_{ob}$ is roughness length of the vegetation for vapor and heat transfer, k = the von Karman constant (0.41), and $u_z$ is the mean wind speed in m/s at height z. Since a water surface does not have form drag effects as does a vegetated surface, the roughness length for heat and vapor transfer was set equal to that for surface rougness.

Wieringa (1992) recently updated roughness length values and reported a value of $z_{om} = 0.0002$ m ($2 \times 10^{-4}$ m) for sea with a free fetch of several km, but indicated that it was dependent on wind speed. Furthermore, he indicated that where a changes in surface roughness occurr, we need to consider surface conditions for several km upwind.

Since our first interest is to estimate evaporation as compared to the USGS estimates, initial clculations were made using $z_{om} = 0.0002$ m. These estimates would be applicable to reservoir evaporation since prior studies have shown that there is little difference in evaporation with effective diameter of the water surface greater than 12 feet (Hely et al., 1966, p C18). Since our interest is also evaporation from canals and rivers, or flowing water, the rougness length for open sea is not appropriate. The Penman-Monteith equation is very sensitive to changes in surface from values from 0.0002 meter to 0.01 m. I used 0.015 for short grass for reference ET estimates. A value of 0.005 was suggested for fallow open country and 0.03 m for level land with low vegetation Wieringa (1992). As a compromise, I used a value of 0.001 m for estimates from flowing water surfaces.

## Priestley and Taylor Equation

Priestley and Taylor (1972) proposed a simplified version of the combination equation for large areas with wet surfaces using data from oceans and wet surfaces. The variables are the same as for the previous equations.

$$E = 1.26 \frac{\Delta}{\Delta + \gamma} R_n \qquad \text{(A-10)}$$

## Equations Used

A printout of the equations as used in the spreadsheet is shown on page A5-A7 and A5-A8.

### APPENDIX A5-B

The following materials are included in Appendix B.

1. Summary of CIMIS data for three sites in the Imperial Irrigation District showing the differences in mean monthly climatic data between the CIMIS files after deleting zeros with the mean values reported by Styles (4 pages).

2. Relationship between clear-day solar radiation and extraterrestrial solar radiation as indicated by mean observed values and as represented by Eq. A-5.

3. Estimated albedo used in estimating daily net radiation based on the data of Wright, ASCE Manual 70, page 137.

4. Tabular summary of annual reference ET values as indicated by CIMIS and by the Penman-Monteith and Penman (1963) estimating methods (1 page).

5. Tabular summary of mean monthly reference ET values as indicated by CIMIS and by the Penman-Monteith and Penman (1963) estimating methods.

7. Copies of the spreadsheet results for the three sites, CIMIS 41, 68 and 87 (6 pages each).

C8: [W4] 'Instrument site:
G8: [W7] 'Water:
H8: [W7] '  hc =
I8: [W7] 0
J8: [W7] 'm
C9: [W4] 'hc, m =
E9: [W7] 0.12
H9: [W7] "zom =
I9: (S0) [W7] 0.0002
J9: [W7] 'm
K9: [W7] "zov =
L9: [W7] "zom =
M9: (S0) [W7] +I9
N9: [W7] 'm
P9: (F1) [W7] (@LN(($N$6-$I$10)/$I$9)*@LN(($K$6-$I$10)/$H$9))/(0.41^2)
C10: [W4] "zom, m =
E10: (F4) [W7] 0.123*E9
H10: [W7] "d =
I10: (F4) [W7] 0
J10: [W7] 'm
K10: [W7] "LAI =
L10: [W7] 24*I8
O10: [W7] "ra =
P10: [W7] ' -----
C11: [W4] "d, m =
E11: (F4) [W7] 2*E9/3
H11: [W7] "rc =
I11: (F2) [W7] 0
J11: (F2) [W7] 's/m
P11: [W7] '   u2
C12: [W4] 'Clear day solar radiation =
H12: [W7] ' Ra x [0.725 + 0.025 cos(2 Pi CD/365 - 2.6)]
O12: [W7] 'Based on maximum Rs values
A19: [W4] +A18+1
B19: [W10] 1987
C19: [W4] 1
D19: [W5] 15
E19: (F2) [W7] 19.55878057
F19: (F0) [W7] +E19/0.041868
G19: (F2) [W7] +E19*(0.725+0.025*@COS(2*@PI*D19/365-2.6))
H19: (F0) [W7] +G19/0.041868
I19: (F0) [W7] 296.6
J19: (F2) [W7] 0.041868*I19
K19: (F2) [W7] +I19/H19
L19: (F1) [W7] 69.322580645
M19: (F1) [W7] (+L19-32)/1.8
N19: (F1) [W7] 34.935483871
O19: (F1) [W7] (+N19-32)/1.8
P19: (F1) [W7] 32.387096774
Q19: (F1) [W7] (+P19-32)/1.8
R19: (F0) [W6] 107.935483871
S19: (F2) [W6] 0.447*(+R19/24)

```
A98: [W4] +A97+1
B98: [W10] 1987
C98: [W4] 1
D98: [W5] 15
E98: (F1) [W7] 0.5*(H19+O19)
F98: (F3) [W7] (0.611*@EXP(17.27*H19/(H19+237.3))+0.611*@EXP(17.27*O19/(O19+237.3)))/2
G98: (F3) [W7] 0.611*@EXP(17.27*O19/(O19+237.3))
H98: (F3) [W7] 4098*(0.611*@EXP(17.27*E98/(E98+237.3)))/(E98+237.3)^2
I98: (F2) [W7] 2.501-(2.361*10^-3)*E98
J98: (F3) [W7] (1.013*$K$5/(0.622*I98))*10^-3
K98: (F3) [W7] +H98/(H98+J98)
L98: (F3) [W7] 0.06+0.021*(1-@COS(2*@PI*D19/365-2.9))
M98: (F2) [W7] (1-L98)*J19
N98: (F1) [W7] 0.97*1.31*(4.903/10^9)*R98^4*(10*G98/R98)^(1/7)
O98: (F2) [W7] 0.97*4.903*(R98)^4/(10^9)
P98: (F2) [W7] (1.126*K19-0.07)*(O98-N98)
Q98: (F2) [W7] +M98-P98
R98: [W6] +E98+273.2
S98: [W6] +Q98/J19
A179: [W4] +A178+1
B179: [W10] 1987
C179: [W4] 1
D179: [W5] 15
E179: [W7] 31
F179: (F3) [W7] 0.611*@EXP(17.27*E98/(E98+237.3))
G179: (F2) [W7] +K98*Q98
H179: (F2) [W7] (1-K98)*6.43*(0.5+0.536*S19)*(F179-G98)
I179: (F2) [W7] +G179+H179
J179: (F2) [W7] +I179/I98
K179: (F2) [W7] +E179*J179/25.4
L179: (F3) [W7] (1+($I$11/$P$9)*S19)*J98
M179: (F3) [W7] +H98/(H98+L179)
N179: (F2) [W7] +M179*Q98
O179: [W7] +J98/(H98+L179)
P179: (F2) [W7] +O179*((185370/$P$9)*I98/(E98+273.2))*S19*(F98-G98)*$P$176
Q179: (F2) [W7] +N179+P179
R179: (F2) [W6] +Q179/I98
S179: (F2) [W6] +E179*R179/25.4
```

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SOURCE:   Hydrologic Regimen of Salton Sea, California. USGS Professional
          Paper 486-C, 1966.
Table 7. - Monthly evaporation from Salton Sea, in inches, determined by
          three methods.

| | 1961 | | | | 1962 | | | |
| Month | Water budget | Energy budget | Mass transfer | Average evap. | Water budget | Energy budget | Mass transfer | Average evap. |
|---|---|---|---|---|---|---|---|---|
| Jan | 1.70 | 1.28 | 1.77 | 1.58 | 2.23 | 1.73 | 2.59 | 2.18 |
| Feb | 3.07 | 2.63 | 3.14 | 2.95 | 2.70 | 2.24 | 2.55 | 2.50 |
| Mar | 4.35 | 4.73 | 5.26 | 4.78 | 3.84 | 3.96 | 4.10 | 3.97 |
| Apr | 6.18 | 6.98 | 6.69 | 6.62 | 5.14 | 6.77 | 6.11 | 6.01 |
| May | 8.47 | 9.60 | 9.34 | 9.14 | 9.00 | 9.67 | 8.86 | 9.18 |
| Jun | 6.93 | 9.09 | 7.85 | 7.96 | 6.73 | 8.50 | 7.22 | 7.48 |
| Jul | 8.17 | 9.18 | 7.55 | 8.30 | 8.81 | 10.07 | 8.12 | 9.00 |
| Aug | 9.36 | 10.09 | 8.61 | 9.35 | 8.83 | 10.02 | 9.29 | 9.38 |
| Sep | 9.08 | 9.55 | 8.78 | 9.14 | 8.10 | 7.56 | 7.56 | 7.74 |
| Oct | 7.36 | 6.74 | 7.15 | 7.08 | 6.77 | 6.16 | 7.42 | 6.78 |
| Nov | 4.45 | 3.62 | 3.82 | 3.96 | 4.94 | 3.21 | 4.67 | 4.27 |
| Dec | 2.32 | 1.53 | 2.22 | 2.02 | 2.93 | 1.07 | 2.64 | 2.21 |
| Annual | 71.4 | 75.0 | 72.2 | 72.9 | 70.0 | 71.0 | 71.1 | 70.7 |

AVERAGES:

| Month | Water budget | Energy budget | Mass transfer | Average evap. | Average x 1.02 | For transfer Average x 1.02 |
|---|---|---|---|---|---|---|
| Jan | 1.97 | 1.51 | 2.18 | 1.88 | 1.92 | 1.92 |
| Feb | 2.89 | 2.44 | 2.85 | 2.72 | 2.78 | 2.78 |
| Mar | 4.10 | 4.35 | 4.68 | 4.37 | 4.46 | 4.46 |
| Apr | 5.66 | 6.88 | 6.40 | 6.31 | 6.44 | 6.44 |
| May | 8.74 | 9.64 | 9.10 | 9.16 | 9.34 | 9.34 |
| Jun | 6.83 | 8.80 | 7.54 | 7.72 | 7.87 | 7.87 |
| Jul | 8.49 | 9.63 | 7.84 | 8.65 | 8.82 | 8.82 |
| Aug | 9.10 | 10.06 | 8.95 | 9.37 | 9.55 | 9.55 |
| Sep | 8.59 | 8.56 | 8.17 | 8.44 | 8.61 | 8.61 |
| Oct | 7.07 | 6.45 | 7.29 | 6.93 | 7.07 | 7.07 |
| Nov | 4.70 | 3.42 | 4.25 | 4.12 | 4.20 | 4.20 |
| Dec | 2.63 | 1.30 | 2.43 | 2.12 | 2.16 | 2.16 |
| Annual | 70.7 | 73.0 | 71.7 | 71.8 | 73.2 | 73.2 |

23-Feb-94 ESTIMATES OF EVAPORATION FROM FRESH WATER RESERVOIRS, IID - 1987-1992   \E-IVAL

========================================================================================

| Year | Station | CIMIS ETo | P-M E | Penman Eo x 0.9 | Priestley- Taylor | Average |
|------|---------|-----------|-------|-----------------|-------------------|---------|
| | | Inches | Inches | Inches | Inches | Inches |
| 1987 | C41 Mulberry | 82.8 | 79.1 | 77.2 | 68.1 | 76.8 |
| | C68 Seeley | | | | | |
| | C87 Meloland | | | | | |
| | Average | 82.8 | 79.1 | 77.2 | 68.1 | 76.8 |
| | | | | | | |
| 1988 | C41 Mulberry | 77.7 | 77.5 | 75.1 | 67.0 | 74.3 |
| | C68 Seeley | 82.6 | 75.3 | 79.1 | 67.9 | 76.2 |
| | C87 Meloland | | | | | |
| | Average | 80.2 | 76.4 | 77.1 | 67.5 | 75.3 |
| | | | | | | |
| 1989 | C41 Mulberry | 75.1 | 80.5 | 78.1 | 68.7 | 75.6 |
| | C68 Seeley | 84.5 | 76.0 | 80.7 | 65.8 | 76.8 |
| | C87 Meloland | | | | | |
| | Average | 79.8 | 78.3 | 79.4 | 67.3 | 76.2 |
| | | | | | | |
| 1990 | C41 Mulberry | 72.1 | 72.9 | 71.0 | 63.5 | 69.9 |
| | C68 Seeley | 77.1 | 76.0 | 79.6 | 67.7 | 75.1 |
| | C87 Meloland | 72.6 | 74.2 | 77.3 | 68.9 | 73.3 |
| | Average | 73.9 | 74.4 | 76.0 | 66.7 | 72.7 |
| | | | | | | |
| 1991 | C41 Mulberry | 67.8 | 73.7 | 71.4 | 67.6 | 70.1 |
| | C68 Seeley | 69.4 | 73.4 | 74.9 | 71.8 | 72.4 |
| | C87 Meloland | 63.9 | 71.4 | 72.1 | 72.5 | 70.0 |
| | Average | 67.0 | 72.8 | 72.8 | 70.6 | 70.8 |
| | | | | | | |
| 1992 | C41 Mulberry | 65.8 | 71.4 | 69.4 | 67.7 | 68.6 |
| | C68 Seeley | 67.9 | 71.6 | 73.7 | 71.7 | 71.2 |
| | C87 Meloland | 66.9 | 71.8 | 73.5 | 72.0 | 71.1 |
| | Average | 66.9 | 71.6 | 72.2 | 70.5 | 70.3 |
| | | | | | | |
| All years | C41 Mulberry | 73.6 | 75.9 | 73.7 | 67.1 | 72.5 |
| | C68 Seeley | 76.3 | 74.5 | 77.6 | 69.0 | 74.3 |
| | C87 Meloland | 67.8 | 72.5 | 74.3 | 71.1 | 71.4 |
| | Average | 72.6 | 74.3 | 75.2 | 69.1 | 72.8 |
| | | | | | | |
| Pct of USGSx1.02 avg: | | 99.1 | 101.4 | 102.7 | 94.4 | 99.4 |

For years 1990-1992:

| | | CIMIS ETo | P-M E | Penman Eo x 0.9 | Priestley- Taylor | Average |
|------|---------|-----------|-------|-----------------|-------------------|---------|
| 1990 | | 73.9 | 74.4 | 76.0 | 66.7 | 74.8 |
| 1991 | | 67.0 | 72.8 | 72.8 | 70.6 | 70.9 |
| 1992 | | 66.9 | 71.6 | 72.2 | 70.5 | 70.2 |
| Average | | 69.3 | 72.9 | 73.7 | 69.3 | 72.0 |
| | | | | | | |
| Pct of 1990-1992 avg: | | 96.3 | 101.4 | 102.4 | 96.3 | 100.0 |
| | | | | | | |
| Pct of USGSavg x 1.02: | | 94.6 | 99.6 | 100.6 | 94.6 | 98.3 |

USGS average (1961 and 1962) x 1.02 =    73.2

| Year | Station | CIMIS ETo | P-M E | Penman Eo x 0.9 | Priestley-Taylor | Average |
|------|---------|-----------|-------|-----------------|------------------|---------|
| | | Inches | Inches | Inches | Inches | Inches |
| 1987 | C41 Mulberry | 82.8 | 90.8 | 85.8 | 68.1 | 81.9 |
| | C68 Seeley | | | | | |
| | C87 Meloland | | | | | |
| | Average | 82.8 | 90.8 | 85.8 | 68.1 | 81.9 |
| | | | | | | |
| 1988 | C41 Mulberry | 77.7 | 88.9 | 83.4 | 67.0 | 79.3 |
| | C68 Seeley | 82.6 | 85.3 | 87.9 | 67.9 | 80.9 |
| | C87 Meloland | | | | | |
| | Average | 80.2 | 87.1 | 85.7 | 67.5 | 80.1 |
| | | | | | | |
| 1989 | C41 Mulberry | 75.1 | 92.7 | 86.8 | 68.7 | 80.8 |
| | C68 Seeley | 84.5 | 87.2 | 89.7 | 65.8 | 81.8 |
| | C87 Meloland | | | | | |
| | Average | 79.8 | 90.0 | 88.3 | 67.3 | 81.3 |
| | | | | | | |
| 1990 | C41 Mulberry | 72.1 | 83.4 | 78.9 | 63.5 | 74.5 |
| | C68 Seeley | 77.1 | 86.5 | 88.4 | 67.7 | 79.9 |
| | C87 Meloland | 72.6 | 83.4 | 85.9 | 68.9 | 77.7 |
| | Average | 73.9 | 84.4 | 84.4 | 66.7 | 77.4 |
| | | | | | | |
| 1991 | C41 Mulberry | 67.8 | 83.0 | 79.3 | 67.6 | 74.4 |
| | C68 Seeley | 69.4 | 81.1 | 83.2 | 71.8 | 76.4 |
| | C87 Meloland | 63.9 | 77.9 | 80.1 | 72.5 | 73.6 |
| | Average | 67.0 | 80.7 | 80.9 | 70.6 | 74.8 |
| | | | | | | |
| 1992 | C41 Mulberry | 65.8 | 79.6 | 77.1 | 67.7 | 72.6 |
| | C68 Seeley | 67.9 | 78.5 | 81.9 | 71.7 | 75.0 |
| | C87 Meloland | 66.9 | 78.6 | 81.7 | 72.0 | 74.8 |
| | Average | 66.9 | 78.9 | 80.2 | 70.5 | 74.1 |
| All years | C41 Mulberry | 73.6 | 86.4 | 81.9 | 67.1 | 77.2 |
| | C68 Seeley | 76.3 | 83.7 | 86.2 | 69.0 | 78.8 |
| | C87 Meloland | 67.8 | 80.0 | 82.6 | 71.1 | 75.4 |
| | Average | 72.6 | 83.4 | 83.6 | 69.1 | 77.1 |
| Pct of USGSx1.02 avg: | | 99.1 | 113.9 | 114.1 | 94.4 | 105.4 |
| For years 1990-1992: | | | | | | |
| 1990 | | 73.9 | 84.4 | 84.4 | 66.7 | 80.9 |
| 1991 | | 67.0 | 80.7 | 80.9 | 70.6 | 76.2 |
| 1992 | | 66.9 | 78.9 | 80.2 | 70.5 | 75.3 |
| Average | | 69.3 | 81.3 | 81.8 | 69.3 | 77.5 |
| Pct of 1990-1992 avg: | | 89.4 | 105.0 | 105.6 | 89.4 | 100.0 |
| Pct of USGSavg x 1.02: | | 94.6 | 111.1 | 111.8 | 94.6 | 105.8 |

USGS average (1961 and 1962) x 1.02 =      73.2

| 252 | SUMMARY OF EVAPORATION ESTIMATES: | | Penman Eo: | | | | Priestley-Taylor: | | Penman-Monteith:zo= 2E-04 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 253 | | CIMIS-41, Mulberry | Rad term | Aero | Eo | | | | | Rad term | Aero | E | |
| 254 | Year | Styles CIMIS, ETo | Inches | Inches | Inches | Pct | Inches | Pct | | Inches | Inches | Inches | Pct |
| 255 | ------- | ------- | ------- | | | ------------- | --------------- | | | ------- | | ----------- | |
| 256 | 1987 | 82.8  112.6% | 53.0 | 31.1 | 85.8 | 104.8% | 68.1 | 101.5% | | 53.0 | 24.6 | 79.1 | 104.3% |
| 257 | 1988 | 77.7  105.6% | 52.1 | 29.7 | 83.4 | 101.8% | 67.0 | 99.8% | | 52.1 | 23.9 | 77.5 | 102.2% |
| 258 | 1989 | 75.1  102.1% | 53.5 | 31.6 | 86.8 | 106.0% | 68.7 | 102.4% | | 53.5 | 25.5 | 80.5 | 106.2% |
| 259 | 1990 | 72.1  98.0% | 49.4 | 28.0 | 78.9 | 96.4% | 63.5 | 94.6% | | 49.4 | 22.1 | 72.9 | 96.1% |
| 260 | 1991 | 67.8  92.2% | 52.6 | 25.2 | 79.3 | 96.8% | 67.6 | 100.7% | | 52.6 | 19.7 | 73.7 | 97.1% |
| 261 | 1992 | 65.8  89.5% | 52.6 | 22.9 | 77.1 | 94.2% | 67.7 | 100.9% | | 52.6 | 17.3 | 71.4 | 94.1% |
| 262 | | --------------- | --------------------------------- | | | | --------------- | | | -------------------------- | | | |
| 263 | Average | 73.6  100.0% | 52.2 | 28.1 | 81.9 | 100.0% | 67.1 | 100.0% | | 52.2 | 22.2 | 75.8 | 100.0% |
| 264 | | | 65.0% | 35.0% | | 73.7 Lake E | | 1.02USGS: | | 70.2% | 29.8% | 75.8 | Lake E |

| 265 | Month | CIMIS Eto | CM/USGS | P-ETo: In/mo | PETo/GS | Pen Eo: In/mo | Px0.9/USGS | In/mo | P-H: In/mo | PM/GS |
|---|---|---|---|---|---|---|---|---|---|---|
| 266 | Jan | 2.62 | 1.36 | 2.74 | 1.42 | 2.48 | 1.16 | 1.92 | 2.26 | 1.18 |
| 267 | Feb | 3.49 | 1.26 | 3.58 | 1.29 | 3.59 | 1.16 | 2.78 | 3.41 | 1.23 |
| 268 | Mar | 5.35 | 1.20 | 5.40 | 1.21 | 5.63 | 1.13 | 4.46 | 5.39 | 1.21 |
| 269 | Apr | 7.04 | 1.09 | 6.98 | 1.08 | 7.53 | 1.05 | 6.44 | 7.17 | 1.11 |
| 270 | May | 9.00 | 0.96 | 9.28 | 0.99 | 10.26 | 0.99 | 9.34 | 9.70 | 1.04 |
| 271 | Jun | 9.43 | 1.20 | 9.46 | 1.20 | 10.79 | 1.23 | 7.87 | 10.03 | 1.27 |
| 272 | Jul | 9.50 | 1.08 | 10.14 | 1.15 | 11.73 | 1.20 | 8.82 | 10.82 | 1.23 |
| 273 | Aug | 8.84 | 0.92 | 9.44 | 0.99 | 10.51 | 0.99 | 9.55 | 9.63 | 1.01 |
| 274 | Sep | 7.32 | 0.85 | 7.74 | 0.90 | 8.01 | 0.84 | 8.61 | 7.24 | 0.84 |
| 275 | Oct | 5.11 | 0.72 | 5.87 | 0.83 | 5.88 | 0.75 | 7.07 | 5.31 | 0.75 |
| 276 | Nov | 3.46 | 0.82 | 3.61 | 0.86 | 3.30 | 0.71 | 4.20 | 2.93 | 0.70 |
| 277 | Dec | 2.34 | 1.08 | 2.42 | 1.12 | 2.15 | 0.90 | 2.16 | 1.94 | 0.90 |
| 278 | Total | 73.5 | 1.00 | 76.7 | 1.05 | 81.9 | 1.01 | 73.2 | 75.8 | 1.04 |

SUMMARY OF EVAPORATION ESTIMATES:

| Year | Styles CIMIS, ETo | | Penman: Aero term Rad term Inches | Aero Inches | Eo Inches | Pct | Priestley-Taylor: Inches | Pct | Penman-Monteith:zo= 2E-04 Rad term Inches | Aero Inches | E Inches | Pct |
|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 1987 | | | | | | | | | | | | |
| 1988 | 82.6 | 108.3% | 52.7 | 33.4 | 87.9 | 102.0% | 67.9 | 98.5% | 52.7 | 21.0 | 75.3 | 101.1% |
| 1989 | 84.5 | 110.7% | 51.2 | 36.8 | 89.7 | 104.0% | 65.8 | 95.4% | 51.2 | 23.4 | 76.0 | 102.1% |
| 1990 | 77.1 | 101.0% | 52.7 | 34.0 | 88.4 | 102.5% | 67.7 | 98.2% | 52.7 | 21.9 | 76.0 | 102.1% |
| 1991 | 69.4 | 91.0% | 55.9 | 25.7 | 83.2 | 96.5% | 71.8 | 104.1% | 55.9 | 16.2 | 73.4 | 98.6% |
| 1992 | 67.9 | 89.0% | 55.7 | 24.5 | 81.9 | 95.0% | 71.7 | 103.9% | 55.7 | 14.4 | 71.6 | 96.2% |
| Average | 76.3 | 100.0% | 53.6 | 30.9 | 86.2 | 100.0% | 69.0 | 100.0% | 53.6 | 19.4 | 74.5 | 100.0% |
| | 69.0 Inches | | 63.5% | 36.5% | 77.6 Lake E | | 1.02USG | 73.5% | 26.5% | | 74.5 Lake E | |

| Month | CIMIS Eto | CM/USGS | P-ETo: In/mo | PETo/GS | Pen Eo: In/mo | Px0.9/USGS | In/mo | P-M: In/mo | PM/GS |
|------|------|------|------|------|------|------|------|------|------|
| Jan | 2.73 | 1.42 | 2.90 | 1.51 | 2.61 | 1.22 | 1.92 | 2.06 | 1.07 |
| Feb | 3.77 | 1.36 | 3.97 | 1.43 | 3.88 | 1.26 | 2.78 | 3.28 | 1.18 |
| Mar | 6.06 | 1.36 | 6.28 | 1.41 | 6.40 | 1.29 | 4.46 | 5.59 | 1.25 |
| Apr | 7.79 | 1.21 | 8.04 | 1.25 | 8.57 | 1.20 | 6.44 | 7.61 | 1.18 |
| May | 9.97 | 1.07 | 10.43 | 1.12 | 11.36 | 1.09 | 9.34 | 10.04 | 1.07 |
| Jun | 10.17 | 1.29 | 10.35 | 1.31 | 11.76 | 1.34 | 7.87 | 10.34 | 1.31 |
| Jul | 9.36 | 1.06 | 9.93 | 1.13 | 11.57 | 1.18 | 8.82 | 10.26 | 1.16 |
| Aug | 8.34 | 0.87 | 9.39 | 0.98 | 10.48 | 0.99 | 9.55 | 9.27 | 0.97 |
| Sep | 7.00 | 0.81 | 7.85 | 0.91 | 8.15 | 0.85 | 8.61 | 7.00 | 0.81 |
| Oct | 5.26 | 0.74 | 6.02 | 0.85 | 5.86 | 0.75 | 7.07 | 4.83 | 0.68 |
| Nov | 3.58 | 0.85 | 3.88 | 0.92 | 3.42 | 0.73 | 4.20 | 2.64 | 0.63 |
| Dec | 2.30 | 1.06 | 2.70 | 1.25 | 2.15 | 0.90 | 2.16 | 1.55 | 0.72 |
| Total | 76.3 | 1.04 | 81.7 | 1.12 | 86.2 | 1.06 | 73.2 | 74.5 | 1.02 |

| | | | | Penman: | | | | | Priestley-Taylor: | | Penman-Monteith:zo= 2E-04 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 252 SUMMARY OF EVAPORATION ESTIMATES: | | | | | | | | | | | | | | |
| 253 | | CIMIS-87, Meloland | | Rad term | Aero | Eo | | | | | Rad term | Aero | E | |
| 254 | Year | Styles | CIMIS | Inches | Inches | Inches | Pct | | Inches | Pct | Inches | Inches | Inches | Pct |
| 255 | ------- | ------- | | ------- | | ------------- | | | ------------- | | ------- | | ------------- | |
| 256 | 1987 | | | | | | | | | | | | | |
| 257 | 1988 | | | | | | | | | | | | | |
| 258 | 1989 | | | | | | | | | | | | | |
| 259 | 1990 | 72.6 | 107.1% | 53.6 | 30.6 | 85.9 | 104.0% | | 68.9 | 96.9% | 53.6 | 19.2 | 74.2 | 102.4% |
| 260 | 1991 | 63.9 | 94.2% | 56.4 | 22.2 | 80.1 | 97.1% | | 72.5 | 101.9% | 56.4 | 13.7 | 71.4 | 98.6% |
| 261 | 1992 | 66.9 | 98.7% | 55.9 | 24.0 | 81.7 | 98.9% | | 72.0 | 101.2% | 55.9 | 14.3 | 71.8 | 99.0% |
| 262 | | ------------- | | ------------------------------ | | | | | ------------- | | ------------------------- | | | |
| 263 | Average | 67.8 | 100.0% | 55.3 | 25.6 | 82.5 | 100.0% | | 71.1 | 100.0% | 55.3 | 15.7 | 72.5 | 100.0% |
| 264 | | | | 68.4% | 31.6% | 74.3 Lake E | | | | 1.02USGS | 77.9% | 22.1% | 72.5 Lake E | |
| 265 | Month | CIMIS ETo | CM/GS | P-ETo: In/mo | PETo/GS | Pen Eo: In/mo | Px0.9/USGS | | | In/mo | | | P-M:In/mo | PM/GS |
| 266 | Jan | 2.37 | 1.23 | 2.90 | 1.51 | 2.48 | 1.16 | | | 1.92 | | | 2.02 | 1.05 |
| 267 | Feb | 3.24 | 1.17 | 3.97 | 1.43 | 3.60 | 1.17 | | | 2.78 | | | 3.09 | 1.11 |
| 268 | Mar | 5.06 | 1.13 | 6.28 | 1.41 | 5.70 | 1.15 | | | 4.46 | | | 5.08 | 1.14 |
| 269 | Apr | 7.02 | 1.09 | 8.04 | 1.25 | 8.00 | 1.12 | | | 6.44 | | | 7.15 | 1.11 |
| 270 | May | 8.63 | 0.92 | 10.43 | 1.12 | 10.36 | 1.00 | | | 9.34 | | | 9.30 | 1.00 |
| 271 | Jun | 8.63 | 1.10 | 10.35 | 1.31 | 10.79 | 1.23 | | | 7.87 | | | 9.59 | 1.22 |
| 272 | Jul | 8.78 | 1.00 | 9.93 | 1.13 | 11.54 | 1.18 | | | 8.82 | | | 10.27 | 1.16 |
| 273 | Aug | 8.04 | 0.84 | 9.39 | 0.98 | 10.55 | 0.99 | | | 9.55 | | | 9.37 | 0.98 |
| 274 | Sep | 6.37 | 0.74 | 7.85 | 0.91 | 8.26 | 0.86 | | | 8.61 | | | 7.23 | 0.84 |
| 275 | Oct | 4.75 | 0.67 | 6.02 | 0.85 | 5.93 | 0.75 | | | 7.07 | | | 5.06 | 0.72 |
| 276 | Nov | 2.99 | 0.71 | 3.88 | 0.92 | 3.31 | 0.71 | | | 4.20 | | | 2.73 | 0.65 |
| 277 | Dec | 1.94 | 0.90 | 2.70 | 1.25 | 2.03 | 0.85 | | | 2.16 | | | 1.59 | 0.74 |
| 278 | Total | 67.8 | 0.93 | 81.7 | 1.12 | 82.5 | 1.01 | | | 73.2 | | | 72.5 | 0.99 |

E, CIMIS-41

Row ==================================================================================================================

```
 3  Column =  C    D     E     F     G     H     I     J     K     L     M     N     O     P     Q     R     S
 4  SITE INPUT DATA:    Lat, degrees = 33.00    or    0.5759 Radians
 5                      Elevation, m =  -50 m     Atm. pressure 101.90 kPa    Energy units = MJ/(m^2 day) = MJ*
 6                      Measurement height:  Temp & dewpoint    2.00 m      Wind   2.00 m
 7                      Surface:      Water
 8          Instrument site:      Water:   hc =     0 m
 9          hc, m =    0.12                 zom = 2E-04 m      zov =  zom = 2E-04 m              504.6
10          zom, m = 0.0148                 d = 0.0000 m      LAI =    0                ra = -----
11          d, m =    0.0800                rc =   0.00 s/m                              u2
12          Clear day solar radiation =    Ra x [0.725 + 0.025 cos(2 Pi CD/365 - 2.6)]    Based on maximum Rs values
13  ----------------------------------------------------------------------------------------------------------------
14  INPUT DATA:   SITE:CIMIS Station 41, Mulberry
15
16                     Ra     Ra    Rso    Rso    Rs    Rs          Maximum temp  Minimum temp Dewpoint temp   Wind run
17       Year Mo  CD  MJ* ly/day  MJ* ly/day ly/day  MJ*    n/N  deg F  deg C  deg F  deg C  deg F  deg C mi/day m/s
18  ----------------------------------------------------------------------------------------------------------------
```

| Year | Mo | CD | Ra MJ* | Ra ly/day | Rso MJ* | Rso ly/day | Rs ly/day | Rs MJ* | n/N | Max deg F | Max deg C | Min deg F | Min deg C | Dew deg F | Dew deg C | Wind mi/day | Wind m/s |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1987 | 1 | 15 | 19.56 | 467 | 13.84 | 331 | 297 | 12.42 | 0.90 | 69.3 | 20.7 | 34.9 | 1.6 | 32.4 | 0.2 | 108 | 2.01 |
| 1987 | 2 | 46 | 24.41 | 583 | 17.55 | 419 | 378 | 15.83 | 0.90 | 73.5 | 23.0 | 41.4 | 5.2 | 36.6 | 2.5 | 138 | 2.56 |
| 1987 | 3 | 74 | 30.65 | 732 | 22.41 | 535 | 508 | 21.28 | 0.95 | 77.5 | 25.3 | 43.0 | 6.1 | 38.1 | 3.4 | 145 | 2.71 |
| 1987 | 4 | 105 | 36.31 | 867 | 26.97 | 644 | 627 | 26.25 | 0.97 | 91.4 | 33.0 | 52.3 | 11.3 | 41.7 | 5.4 | 124 | 2.31 |
| 1987 | 5 | 135 | 39.96 | 954 | 29.93 | 715 | 671 | 28.09 | 0.94 | 93.6 | 34.2 | 58.6 | 14.8 | 42.8 | 6.0 | 154 | 2.86 |
| 1987 | 6 | 166 | 41.36 | 988 | 30.98 | 740 | 713 | 29.86 | 0.96 | 105.3 | 40.7 | 66.2 | 19.0 | 40.1 | 4.5 | 136 | 2.54 |
| 1987 | 7 | 196 | 40.60 | 970 | 30.16 | 720 | 701 | 29.35 | 0.97 | 105.4 | 40.8 | 69.8 | 21.0 | 51.3 | 10.7 | 140 | 2.60 |
| 1987 | 8 | 227 | 37.69 | 900 | 27.57 | 658 | 603 | 25.26 | 0.92 | 104.9 | 40.5 | 74.2 | 23.4 | 61.3 | 16.3 | 154 | 2.87 |
| 1987 | 9 | 258 | 32.84 | 784 | 23.59 | 563 | 517 | 21.63 | 0.92 | 100.6 | 38.1 | 62.7 | 17.0 | 50.2 | 10.1 | 124 | 2.31 |
| 1987 | 10 | 288 | 26.70 | 638 | 18.89 | 451 | 360 | 15.09 | 0.80 | 94.0 | 34.5 | 60.6 | 15.9 | 59.2 | 15.1 | 99 | 1.84 |
| 1987 | 11 | 319 | 21.02 | 502 | 14.73 | 352 | 313 | 13.09 | 0.89 | 77.2 | 25.1 | 44.9 | 7.1 | 47.9 | 8.8 | 82 | 1.54 |
| 1987 | 12 | 349 | 18.14 | 433 | 12.72 | 304 | 243 | 10.16 | 0.80 | 65.0 | 18.4 | 35.6 | 2.0 | 37.9 | 3.3 | 103 | 1.91 |
| 1988 | 1 | 15 | 19.56 | 467 | 13.84 | 331 | 293 | 12.27 | 0.89 | 69.3 | 20.7 | 35.5 | 1.9 | 37.1 | 2.8 | 106 | 1.98 |
| 1988 | 2 | 46 | 24.41 | 583 | 17.55 | 419 | 393 | 16.47 | 0.94 | 76.7 | 24.8 | 40.2 | 4.6 | 41.3 | 5.2 | 108 | 2.02 |
| 1988 | 3 | 74 | 30.65 | 732 | 22.41 | 535 | 461 | 19.30 | 0.86 | 82.3 | 28.0 | 43.3 | 6.3 | 38.7 | 3.7 | 125 | 2.33 |
| 1988 | 4 | 105 | 36.31 | 867 | 26.97 | 644 | 544 | 22.78 | 0.84 | 84.7 | 29.3 | 48.2 | 9.0 | 47.2 | 8.5 | 126 | 2.35 |
| 1988 | 5 | 135 | 39.96 | 954 | 29.93 | 715 | 573 | 24.01 | 0.80 | 93.1 | 34.0 | 54.5 | 12.5 | 42.6 | 5.9 | 186 | 3.46 |
| 1988 | 6 | 166 | 41.36 | 988 | 30.98 | 740 | 701 | 29.35 | 0.95 | 101.5 | 38.6 | 62.7 | 17.1 | 49.8 | 9.9 | 136 | 2.54 |
| 1988 | 7 | 196 | 40.60 | 970 | 30.16 | 720 | 661 | 27.65 | 0.92 | 106.5 | 41.4 | 73.9 | 23.3 | 64.2 | 17.9 | 149 | 2.77 |
| 1988 | 8 | 227 | 37.69 | 900 | 27.57 | 658 | 624 | 26.14 | 0.95 | 105.1 | 40.6 | 73.2 | 22.9 | 62.9 | 17.2 | 124 | 2.31 |
| 1988 | 9 | 258 | 32.84 | 784 | 23.59 | 563 | 431 | 18.03 | 0.76 | 102.5 | 39.2 | 66.2 | 19.0 | 52.0 | 11.1 | 119 | 2.21 |
| 1988 | 10 | 288 | 26.70 | 638 | 18.89 | 451 | 421 | 17.61 | 0.93 | 96.0 | 35.6 | 61.2 | 16.2 | 55.7 | 13.2 | 102 | 1.90 |
| 1988 | 11 | 319 | 21.02 | 502 | 14.73 | 352 | 310 | 12.98 | 0.88 | 78.5 | 25.8 | 44.3 | 6.8 | 40.5 | 4.7 | 114 | 2.12 |
| 1988 | 12 | 349 | 18.14 | 433 | 12.72 | 304 | 291 | 12.18 | 0.96 | 70.3 | 21.3 | 34.9 | 1.6 | 31.8 | -0.1 | 111 | 2.06 |
| 1989 | 1 | 15 | 19.56 | 467 | 13.84 | 331 | 285 | 11.93 | 0.86 | 69.1 | 20.6 | 34.8 | 1.5 | 32.7 | 0.4 | 101 | 1.89 |
| 1989 | 2 | 46 | 24.41 | 583 | 17.55 | 419 | 395 | 16.52 | 0.94 | 75.0 | 23.9 | 39.2 | 4.0 | 40.2 | 4.6 | 123 | 2.28 |
| 1989 | 3 | 74 | 30.65 | 732 | 22.41 | 535 | 429 | 17.98 | 0.80 | 88.3 | 31.3 | 47.6 | 8.7 | 47.7 | 8.7 | 113 | 2.10 |
| 1989 | 4 | 105 | 36.31 | 867 | 26.97 | 644 | 633 | 26.50 | 0.98 | 92.4 | 33.6 | 53.1 | 11.7 | 48.6 | 9.2 | 120 | 2.24 |
| 1989 | 5 | 135 | 39.96 | 954 | 29.93 | 715 | 693 | 29.00 | 0.97 | 95.3 | 35.2 | 57.0 | 13.9 | 41.4 | 5.2 | 161 | 3.00 |
| 1989 | 6 | 166 | 41.36 | 988 | 30.98 | 740 | 713 | 29.84 | 0.96 | 104.8 | 40.5 | 62.8 | 17.1 | 41.8 | 5.4 | 146 | 2.72 |
| 1989 | 7 | 196 | 40.60 | 970 | 30.16 | 720 | 656 | 27.48 | 0.91 | 108.5 | 42.5 | 71.5 | 21.9 | 53.2 | 11.8 | 141 | 2.63 |
| 1989 | 8 | 227 | 37.69 | 900 | 27.57 | 658 | 624 | 26.14 | 0.95 | 104.4 | 40.2 | 70.4 | 21.3 | 61.5 | 16.4 | 129 | 2.40 |
| 1989 | 9 | 258 | 32.84 | 784 | 23.59 | 563 | 543 | 22.72 | 0.96 | 102.7 | 39.3 | 65.3 | 18.5 | 50.3 | 10.1 | 128 | 2.37 |
| 1989 | 10 | 288 | 26.70 | 638 | 18.89 | 451 | 420 | 17.60 | 0.93 | 91.3 | 32.9 | 54.8 | 12.7 | 44.5 | 6.9 | 113 | 2.11 |
| 1989 | 11 | 319 | 21.02 | 502 | 14.73 | 352 | 334 | 13.96 | 0.95 | 81.1 | 27.3 | 43.0 | 6.1 | 40.4 | 4.6 | 103 | 1.93 |
| 1989 | 12 | 349 | 18.14 | 433 | 12.72 | 304 | 274 | 11.47 | 0.90 | 71.9 | 22.2 | 32.8 | 0.5 | 34.9 | 1.6 | 90 | 1.69 |

| 55 | 1990 | 1 | 15 | 19.56 | 467 | 13.84 | 331 | 244 | 10.20 | 0.74 | 72.3 | 22.4 | 34.8 | 1.5 | 37.1 | 2.8 | 103 | 1.91 |
|----|------|----|-----|-------|-----|-------|-----|-----|-------|------|-------|------|------|------|------|------|-----|------|
| 56 | 1990 | 2 | 46 | 24.41 | 583 | 17.55 | 419 | 362 | 15.16 | 0.86 | 73.0 | 22.8 | 36.1 | 2.3 | 36.6 | 2.6 | 123 | 2.29 |
| 57 | 1990 | 3 | 74 | 30.65 | 732 | 22.41 | 535 | 490 | 20.52 | 0.92 | 81.3 | 27.4 | 44.8 | 7.1 | 43.8 | 6.5 | 132 | 2.46 |
| 58 | 1990 | 4 | 105 | 36.31 | 867 | 26.97 | 644 | 490 | 20.50 | 0.76 | 86.6 | 30.3 | 52.5 | 11.4 | 50.6 | 10.3 | 125 | 2.32 |
| 59 | 1990 | 5 | 135 | 39.96 | 954 | 29.93 | 715 | 660 | 27.63 | 0.92 | 92.2 | 33.4 | 55.4 | 13.0 | 41.9 | 5.5 | 162 | 3.03 |
| 60 | 1990 | 6 | 166 | 41.36 | 988 | 30.98 | 740 | 672 | 28.14 | 0.91 | 103.5 | 39.7 | 64.3 | 17.9 | 48.9 | 9.4 | 121 | 2.26 |
| 61 | 1990 | 7 | 196 | 40.60 | 970 | 30.16 | 720 | 579 | 24.24 | 0.80 | 105.5 | 40.8 | 74.1 | 23.4 | 61.3 | 16.3 | 144 | 2.68 |
| 62 | 1990 | 8 | 227 | 37.69 | 900 | 27.57 | 658 | 425 | 17.77 | 0.64 | 101.1 | 38.4 | 72.2 | 22.3 | 63.2 | 17.3 | 117 | 2.17 |
| 63 | 1990 | 9 | 258 | 32.84 | 784 | 23.59 | 563 | 538 | 22.52 | 0.95 | 99.7 | 37.6 | 68.7 | 20.4 | 62.5 | 17.0 | 112 | 2.09 |
| 64 | 1990 | 10 | 288 | 26.70 | 638 | 18.89 | 451 | 439 | 18.39 | 0.97 | 91.1 | 32.8 | 55.5 | 13.0 | 49.7 | 9.8 | 94 | 1.74 |
| 65 | 1990 | 11 | 319 | 21.02 | 502 | 14.73 | 352 | 246 | 10.29 | 0.70 | 77.0 | 25.0 | 44.8 | 7.1 | 36.9 | 2.7 | 114 | 2.12 |
| 66 | 1990 | 12 | 349 | 18.14 | 433 | 12.72 | 304 | 262 | 10.97 | 0.86 | 66.6 | 19.2 | 34.2 | 1.2 | 28.2 | -2.1 | 107 | 2.00 |
| 67 | 1991 | 1 | 15 | 19.56 | 467 | 13.84 | 331 | 209 | 8.77 | 0.63 | 67.6 | 19.8 | 38.4 | 3.5 | 35.2 | 1.8 | 90 | 1.68 |
| 68 | 1991 | 2 | 46 | 24.41 | 583 | 17.55 | 419 | 356 | 14.91 | 0.85 | 78.4 | 25.8 | 42.9 | 6.0 | 46.2 | 7.9 | 101 | 1.88 |
| 69 | 1991 | 3 | 74 | 30.65 | 732 | 22.41 | 535 | 450 | 18.83 | 0.84 | 71.7 | 22.0 | 43.4 | 6.3 | 43.1 | 6.2 | 145 | 2.70 |
| 70 | 1991 | 4 | 105 | 36.31 | 867 | 26.97 | 644 | 599 | 25.07 | 0.93 | 83.3 | 28.5 | 48.0 | 8.9 | 46.9 | 8.3 | 140 | 2.61 |
| 71 | 1991 | 5 | 135 | 39.96 | 954 | 29.93 | 715 | 699 | 29.24 | 0.98 | 89.2 | 31.8 | 53.3 | 11.8 | 50.7 | 10.4 | 145 | 2.71 |
| 72 | 1991 | 6 | 166 | 41.36 | 988 | 30.98 | 740 | 574 | 24.02 | 0.78 | 96.3 | 35.7 | 62.2 | 16.8 | 55.4 | 13.0 | 132 | 2.46 |
| 73 | 1991 | 7 | 196 | 40.60 | 970 | 30.16 | 720 | 655 | 27.41 | 0.91 | 102.3 | 39.1 | 69.7 | 20.9 | 62.9 | 17.2 | 122 | 2.27 |
| 74 | 1991 | 8 | 227 | 37.69 | 900 | 27.57 | 658 | 611 | 25.59 | 0.93 | 104.2 | 40.1 | 73.4 | 23.0 | 62.3 | 16.8 | 122 | 2.27 |
| 75 | 1991 | 9 | 258 | 32.84 | 784 | 23.59 | 563 | 495 | 20.70 | 0.88 | 99.7 | 37.6 | 70.4 | 21.4 | 63.8 | 17.7 | 113 | 2.11 |
| 76 | 1991 | 10 | 288 | 26.70 | 638 | 18.89 | 451 | 400 | 16.73 | 0.89 | 93.5 | 34.2 | 60.3 | 15.7 | 53.9 | 12.2 | 121 | 2.25 |
| 77 | 1991 | 11 | 319 | 21.02 | 502 | 14.73 | 352 | 255 | 10.66 | 0.72 | 77.6 | 25.3 | 46.0 | 7.8 | 31.8 | -0.1 | 121 | 2.25 |
| 78 | 1991 | 12 | 349 | 18.14 | 433 | 12.72 | 304 | 222 | 9.31 | 0.73 | 66.5 | 19.2 | 41.6 | 5.3 | 41.6 | 5.3 | 87 | 1.61 |
| 79 | 1992 | 1 | 15 | 19.56 | 467 | 13.84 | 331 | 272 | 11.38 | 0.82 | 68.6 | 20.3 | 37.5 | 3.1 | 37.8 | 3.2 | 91 | 1.70 |
| 80 | 1992 | 2 | 46 | 24.41 | 583 | 17.55 | 419 | 339 | 14.20 | 0.81 | 74.0 | 23.4 | 45.7 | 7.6 | 47.0 | 8.4 | 106 | 1.97 |
| 81 | 1992 | 3 | 74 | 30.65 | 732 | 22.41 | 535 | 426 | 17.83 | 0.80 | 75.1 | 23.9 | 46.8 | 8.2 | 51.1 | 10.6 | 98 | 1.82 |
| 82 | 1992 | 4 | 105 | 36.31 | 867 | 26.97 | 644 | 493 | 20.64 | 0.77 | 89.2 | 31.8 | 53.6 | 12.0 | 52.7 | 11.5 | 92 | 1.71 |
| 83 | 1992 | 5 | 135 | 39.96 | 954 | 29.93 | 715 | 636 | 26.61 | 0.89 | 93.6 | 34.2 | 61.2 | 16.2 | 58.0 | 14.5 | 110 | 2.04 |
| 84 | 1992 | 6 | 166 | 41.36 | 988 | 30.98 | 740 | 627 | 26.24 | 0.85 | 99.9 | 37.7 | 64.0 | 17.8 | 58.6 | 14.8 | 127 | 2.37 |
| 85 | 1992 | 7 | 196 | 40.60 | 970 | 30.16 | 720 | 633 | 26.49 | 0.88 | 103.8 | 39.9 | 73.8 | 23.2 | 65.0 | 18.4 | 135 | 2.51 |
| 86 | 1992 | 8 | 227 | 37.69 | 900 | 27.57 | 658 | 584 | 24.46 | 0.89 | 105.1 | 40.6 | 78.1 | 25.6 | 69.7 | 20.9 | 145 | 2.70 |
| 87 | 1992 | 9 | 258 | 32.84 | 784 | 23.59 | 563 | 389 | 16.30 | 0.69 | 104.0 | 40.0 | 71.0 | 21.7 | 61.4 | 16.3 | 108 | 2.01 |
| 88 | 1992 | 10 | 288 | 26.70 | 638 | 18.89 | 451 | 389 | 16.27 | 0.86 | 92.0 | 33.3 | 60.5 | 15.8 | 54.8 | 12.7 | 106 | 1.98 |
| 89 | 1992 | 11 | 319 | 21.02 | 502 | 14.73 | 352 | 308 | 12.87 | 0.87 | 75.2 | 24.0 | 41.7 | 5.4 | 36.7 | 2.6 | 106 | 1.97 |
| 90 | 1992 | 12 | 349 | 18.14 | 433 | 12.72 | 304 | 235 | 9.83 | 0.77 | 62.9 | 17.2 | 36.0 | 2.2 | 39.5 | 4.1 | 97 | 1.80 |
| 91 | ----- | | | | | | | | | | | | | | | | | |

| | | | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 93 BASIC CALCULATIONS: | | | | | | delta(D) | | gamma(g) | | 0.0994 | | | | | | | |
| | | | Tavg | eo | ed | | Lamda(L) | | f(Tavg) | | Rns | Ld | Lu | Rb | Rn | TavgK | |
| Year | Mo | CD | C | kPa | kPa | kPa/C | MJ/kg | kPa/C | D/(D+g) | Albedo | MJ* | MJ* | MJ* | MJ* | MJ* | K | Rn/Rs |
| 1987 | 1 | 15 | 11.2 | 1.568 | 0.621 | 0.088 | 2.47 | 0.067 | 0.568 | 0.099 | 11.18 | 23.6 | 31.11 | 7.06 | 4.12 | 284.3 | 0.331 |
| 1987 | 2 | 46 | 14.1 | 1.852 | 0.734 | 0.105 | 2.47 | 0.067 | 0.609 | 0.092 | 14.37 | 25.1 | 32.42 | 6.87 | 7.50 | 287.3 | 0.473 |
| 1987 | 3 | 74 | 15.7 | 2.083 | 0.778 | 0.114 | 2.46 | 0.067 | 0.629 | 0.082 | 19.53 | 25.9 | 33.13 | 7.23 | 12.30 | 288.8 | 0.578 |
| 1987 | 4 | 105 | 22.1 | 3.182 | 0.895 | 0.162 | 2.45 | 0.068 | 0.705 | 0.071 | 24.37 | 28.8 | 36.18 | 7.61 | 16.77 | 295.3 | 0.638 |
| 1987 | 5 | 135 | 24.5 | 3.535 | 0.937 | 0.184 | 2.44 | 0.068 | 0.730 | 0.063 | 26.31 | 29.9 | 37.35 | 7.40 | 18.91 | 297.6 | 0.673 |
| 1987 | 6 | 166 | 29.9 | 4.935 | 0.843 | 0.242 | 2.43 | 0.068 | 0.780 | 0.060 | 28.07 | 31.5 | 40.12 | 8.75 | 19.32 | 303.0 | 0.647 |
| 1987 | 7 | 196 | 30.9 | 5.082 | 1.290 | 0.254 | 2.43 | 0.068 | 0.788 | 0.062 | 27.52 | 33.9 | 40.66 | 6.92 | 20.60 | 304.0 | 0.701 |
| 1987 | 8 | 227 | 32.0 | 5.227 | 1.849 | 0.268 | 2.43 | 0.068 | 0.797 | 0.070 | 23.50 | 36.2 | 41.24 | 4.85 | 18.65 | 305.1 | 0.738 |
| 1987 | 9 | 258 | 27.6 | 4.306 | 1.239 | 0.216 | 2.44 | 0.068 | 0.760 | 0.080 | 19.89 | 32.3 | 38.93 | 6.35 | 13.54 | 300.7 | 0.626 |
| 1987 | 10 | 288 | 25.2 | 3.632 | 1.716 | 0.190 | 2.44 | 0.068 | 0.737 | 0.091 | 13.72 | 32.8 | 37.69 | 4.03 | 9.69 | 298.3 | 0.642 |
| 1987 | 11 | 319 | 16.1 | 2.101 | 1.135 | 0.117 | 2.46 | 0.067 | 0.635 | 0.099 | 11.79 | 27.5 | 33.33 | 5.43 | 6.36 | 289.3 | 0.486 |
| 1987 | 12 | 349 | 10.2 | 1.408 | 0.773 | 0.083 | 2.48 | 0.067 | 0.554 | 0.102 | 9.13 | 24.0 | 30.66 | 5.52 | 3.61 | 283.3 | 0.354 |
| 1988 | 1 | 15 | 11.3 | 1.572 | 0.749 | 0.089 | 2.47 | 0.067 | 0.570 | 0.099 | 11.05 | 24.3 | 31.17 | 6.39 | 4.66 | 284.5 | 0.379 |
| 1988 | 2 | 46 | 14.7 | 1.989 | 0.883 | 0.108 | 2.47 | 0.067 | 0.616 | 0.092 | 14.96 | 26.0 | 32.67 | 6.56 | 8.39 | 287.8 | 0.509 |
| 1988 | 3 | 74 | 17.1 | 2.362 | 0.797 | 0.124 | 2.46 | 0.067 | 0.647 | 0.082 | 17.72 | 26.5 | 33.78 | 6.57 | 11.14 | 290.3 | 0.577 |
| 1988 | 4 | 105 | 19.1 | 2.612 | 1.107 | 0.138 | 2.46 | 0.068 | 0.672 | 0.071 | 21.15 | 28.5 | 34.74 | 5.49 | 15.66 | 292.3 | 0.687 |
| 1988 | 5 | 135 | 23.2 | 3.381 | 0.930 | 0.172 | 2.45 | 0.068 | 0.717 | 0.063 | 22.49 | 29.3 | 36.72 | 6.15 | 16.33 | 296.4 | 0.680 |
| 1988 | 6 | 166 | 27.8 | 4.394 | 1.218 | 0.218 | 2.44 | 0.068 | 0.762 | 0.060 | 27.59 | 32.4 | 39.05 | 6.68 | 20.91 | 301.0 | 0.712 |
| 1988 | 7 | 196 | 32.3 | 5.406 | 2.052 | 0.273 | 2.42 | 0.068 | 0.800 | 0.062 | 25.93 | 36.9 | 41.45 | 4.36 | 21.57 | 305.5 | 0.779 |
| 1988 | 8 | 227 | 31.8 | 5.210 | 1.957 | 0.266 | 2.43 | 0.068 | 0.795 | 0.070 | 24.32 | 36.4 | 41.13 | 4.72 | 19.59 | 304.9 | 0.749 |
| 1988 | 9 | 258 | 29.1 | 4.626 | 1.321 | 0.233 | 2.43 | 0.068 | 0.773 | 0.080 | 16.58 | 33.3 | 39.71 | 5.10 | 11.48 | 302.2 | 0.636 |
| 1988 | 10 | 288 | 25.9 | 3.824 | 1.515 | 0.198 | 2.44 | 0.068 | 0.744 | 0.091 | 16.01 | 32.6 | 38.06 | 5.39 | 10.62 | 299.0 | 0.603 |
| 1988 | 11 | 319 | 16.3 | 2.161 | 0.855 | 0.118 | 2.46 | 0.067 | 0.637 | 0.099 | 11.70 | 26.5 | 33.43 | 6.41 | 5.29 | 289.5 | 0.407 |
| 1988 | 12 | 349 | 11.5 | 1.610 | 0.605 | 0.090 | 2.47 | 0.067 | 0.572 | 0.102 | 10.94 | 23.6 | 31.23 | 7.69 | 3.25 | 284.6 | 0.266 |
| 1989 | 1 | 15 | 11.1 | 1.555 | 0.629 | 0.088 | 2.47 | 0.067 | 0.566 | 0.099 | 10.74 | 23.6 | 31.05 | 6.71 | 4.03 | 284.2 | 0.337 |
| 1989 | 2 | 46 | 13.9 | 1.891 | 0.846 | 0.103 | 2.47 | 0.067 | 0.606 | 0.092 | 15.01 | 25.6 | 32.33 | 6.66 | 8.34 | 287.1 | 0.504 |
| 1989 | 3 | 74 | 20.0 | 2.844 | 1.126 | 0.145 | 2.45 | 0.068 | 0.681 | 0.082 | 16.50 | 28.9 | 35.14 | 5.20 | 11.30 | 293.1 | 0.628 |
| 1989 | 4 | 105 | 22.6 | 3.285 | 1.167 | 0.167 | 2.45 | 0.068 | 0.711 | 0.071 | 24.61 | 30.1 | 36.43 | 6.59 | 18.02 | 295.8 | 0.679 |
| 1989 | 5 | 135 | 24.5 | 3.632 | 0.886 | 0.184 | 2.44 | 0.068 | 0.731 | 0.063 | 27.16 | 29.6 | 37.37 | 7.90 | 19.26 | 297.7 | 0.664 |
| 1989 | 6 | 166 | 28.8 | 4.758 | 0.899 | 0.229 | 2.43 | 0.068 | 0.771 | 0.060 | 28.05 | 31.4 | 39.56 | 8.31 | 19.74 | 301.9 | 0.661 |
| 1989 | 7 | 196 | 32.2 | 5.521 | 1.381 | 0.271 | 2.42 | 0.068 | 0.799 | 0.062 | 25.77 | 34.8 | 41.37 | 6.26 | 19.51 | 305.3 | 0.709 |
| 1989 | 8 | 227 | 30.8 | 5.004 | 1.861 | 0.253 | 2.43 | 0.068 | 0.787 | 0.070 | 24.32 | 35.7 | 40.61 | 4.90 | 19.42 | 303.9 | 0.742 |
| 1989 | 9 | 258 | 28.9 | 4.617 | 1.241 | 0.230 | 2.43 | 0.068 | 0.771 | 0.080 | 20.90 | 32.9 | 39.61 | 6.82 | 14.07 | 302.0 | 0.619 |
| 1989 | 10 | 288 | 22.8 | 3.240 | 0.997 | 0.168 | 2.45 | 0.068 | 0.713 | 0.091 | 16.00 | 29.5 | 36.51 | 6.90 | 9.10 | 296.0 | 0.517 |
| 1989 | 11 | 319 | 16.7 | 2.282 | 0.851 | 0.121 | 2.46 | 0.067 | 0.642 | 0.099 | 12.58 | 26.6 | 33.59 | 6.99 | 5.59 | 289.8 | 0.400 |
| 1989 | 12 | 349 | 11.3 | 1.652 | 0.687 | 0.089 | 2.47 | 0.067 | 0.570 | 0.102 | 10.30 | 24.0 | 31.16 | 6.79 | 3.51 | 284.5 | 0.306 |
| 1990 | 1 | 15 | 12.0 | 1.696 | 0.750 | 0.092 | 2.47 | 0.067 | 0.579 | 0.099 | 9.18 | 24.5 | 31.45 | 5.28 | 3.90 | 285.1 | 0.382 |
| 1990 | 2 | 46 | 12.5 | 1.747 | 0.736 | 0.095 | 2.47 | 0.067 | 0.587 | 0.092 | 13.77 | 24.6 | 31.70 | 6.39 | 7.38 | 285.7 | 0.486 |
| 1990 | 3 | 74 | 17.2 | 2.328 | 0.971 | 0.125 | 2.46 | 0.067 | 0.649 | 0.082 | 18.84 | 27.3 | 33.85 | 6.31 | 12.53 | 290.4 | 0.610 |
| 1990 | 4 | 105 | 20.9 | 2.836 | 1.254 | 0.152 | 2.45 | 0.068 | 0.691 | 0.071 | 19.04 | 29.7 | 35.56 | 4.62 | 14.42 | 294.0 | 0.703 |
| 1990 | 5 | 135 | 23.2 | 3.327 | 0.904 | 0.172 | 2.45 | 0.068 | 0.717 | 0.063 | 25.88 | 29.2 | 36.71 | 7.27 | 18.61 | 296.4 | 0.673 |
| 1990 | 6 | 166 | 28.8 | 4.661 | 1.180 | 0.229 | 2.43 | 0.068 | 0.771 | 0.060 | 26.45 | 32.6 | 39.57 | 6.62 | 19.83 | 302.0 | 0.704 |
| 1990 | 7 | 196 | 32.1 | 5.287 | 1.853 | 0.270 | 2.43 | 0.068 | 0.798 | 0.062 | 22.73 | 36.3 | 41.31 | 4.21 | 18.52 | 305.2 | 0.763 |
| 1990 | 8 | 227 | 30.4 | 4.739 | 1.981 | 0.248 | 2.43 | 0.068 | 0.784 | 0.070 | 16.53 | 35.8 | 40.39 | 2.99 | 13.54 | 303.5 | 0.761 |
| 1990 | 9 | 258 | 29.0 | 4.438 | 1.934 | 0.231 | 2.43 | 0.068 | 0.772 | 0.080 | 20.71 | 35.1 | 39.66 | 4.60 | 16.11 | 302.1 | 0.715 |
| 1990 | 10 | 288 | 22.9 | 3.245 | 1.214 | 0.169 | 2.45 | 0.068 | 0.714 | 0.091 | 16.72 | 30.4 | 36.58 | 6.38 | 10.34 | 296.1 | 0.562 |
| 1990 | 11 | 319 | 16.1 | 2.089 | 0.742 | 0.117 | 2.46 | 0.067 | 0.634 | 0.099 | 9.27 | 25.8 | 33.29 | 5.34 | 3.93 | 289.2 | 0.382 |
| 1990 | 12 | 349 | 10.2 | 1.447 | 0.523 | 0.083 | 2.48 | 0.067 | 0.554 | 0.102 | 9.85 | 22.7 | 30.68 | 7.17 | 2.68 | 283.4 | 0.244 |
| 1991 | 1 | 15 | 11.7 | 1.547 | 0.696 | 0.091 | 2.47 | 0.067 | 0.575 | 0.099 | 7.90 | 24.1 | 31.31 | 4.62 | 3.28 | 284.8 | 0.373 |

| 147 | 1991 | 2 | 46 | 15.9 | 2.128 | 1.064 | 0.116 | 2.46 | 0.067 | 0.632 | 0.092 | 13.54 | 27.2 | 33.22 | 5.38 | 8.16 | 289.1 | 0.547 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 148 | 1991 | 3 | 74 | 14.2 | 1.804 | 0.947 | 0.105 | 2.47 | 0.067 | 0.609 | 0.082 | 17.28 | 26.1 | 32.44 | 5.55 | 11.73 | 287.3 | 0.622 |
| 149 | 1991 | 4 | 105 | 18.7 | 2.514 | 1.093 | 0.135 | 2.46 | 0.068 | 0.666 | 0.071 | 23.29 | 28.3 | 34.52 | 6.09 | 17.20 | 291.8 | 0.685 |
| 150 | 1991 | 5 | 135 | 21.8 | 3.042 | 1.260 | 0.159 | 2.45 | 0.068 | 0.702 | 0.063 | 27.39 | 30.1 | 36.02 | 6.13 | 21.26 | 295.0 | 0.727 |
| 151 | 1991 | 6 | 166 | 26.2 | 3.881 | 1.500 | 0.201 | 2.44 | 0.068 | 0.747 | 0.060 | 22.58 | 32.7 | 38.24 | 4.48 | 18.10 | 299.4 | 0.753 |
| 152 | 1991 | 7 | 196 | 30.0 | 4.748 | 1.957 | 0.243 | 2.43 | 0.068 | 0.781 | 0.062 | 25.70 | 35.6 | 40.19 | 4.38 | 21.32 | 303.2 | 0.777 |
| 153 | 1991 | 8 | 227 | 31.5 | 5.111 | 1.917 | 0.263 | 2.43 | 0.068 | 0.793 | 0.070 | 23.80 | 36.2 | 41.02 | 4.70 | 19.10 | 304.7 | 0.746 |
| 154 | 1991 | 9 | 258 | 29.5 | 4.512 | 2.022 | 0.237 | 2.43 | 0.068 | 0.776 | 0.080 | 19.04 | 35.5 | 39.91 | 4.03 | 15.01 | 302.6 | 0.724 |
| 155 | 1991 | 10 | 288 | 24.9 | 3.581 | 1.420 | 0.188 | 2.44 | 0.068 | 0.735 | 0.091 | 15.21 | 31.9 | 37.58 | 5.30 | 9.92 | 298.1 | 0.592 |
| 156 | 1991 | 11 | 319 | 16.6 | 2.146 | 0.606 | 0.120 | 2.46 | 0.067 | 0.640 | 0.099 | 9.61 | 25.3 | 33.53 | 6.15 | 3.46 | 289.7 | 0.324 |
| 157 | 1991 | 12 | 349 | 12.2 | 1.556 | 0.894 | 0.094 | 2.47 | 0.067 | 0.583 | 0.102 | 8.36 | 25.2 | 31.57 | 4.80 | 3.57 | 285.4 | 0.382 |
| 158 | 1992 | 1 | 15 | 11.7 | 1.575 | 0.770 | 0.091 | 2.47 | 0.067 | 0.575 | 0.099 | 10.25 | 24.5 | 31.33 | 5.85 | 4.41 | 284.9 | 0.387 |
| 159 | 1992 | 2 | 46 | 15.5 | 1.958 | 1.099 | 0.113 | 2.46 | 0.067 | 0.626 | 0.092 | 12.89 | 27.1 | 33.03 | 4.96 | 7.93 | 288.6 | 0.558 |
| 160 | 1992 | 3 | 74 | 16.1 | 2.031 | 1.280 | 0.117 | 2.46 | 0.067 | 0.634 | 0.082 | 16.36 | 27.9 | 33.30 | 4.42 | 11.94 | 289.2 | 0.669 |
| 161 | 1992 | 4 | 105 | 21.9 | 3.046 | 1.358 | 0.160 | 2.45 | 0.068 | 0.703 | 0.071 | 19.17 | 30.4 | 36.05 | 4.46 | 14.71 | 295.0 | 0.712 |
| 162 | 1992 | 5 | 135 | 25.2 | 3.618 | 1.648 | 0.191 | 2.44 | 0.068 | 0.738 | 0.063 | 24.92 | 32.7 | 37.72 | 4.70 | 20.22 | 298.4 | 0.759 |
| 163 | 1992 | 6 | 166 | 27.7 | 4.279 | 1.680 | 0.217 | 2.44 | 0.068 | 0.761 | 0.060 | 24.66 | 33.8 | 39.01 | 4.57 | 20.09 | 300.9 | 0.765 |
| 164 | 1992 | 7 | 196 | 31.6 | 5.090 | 2.111 | 0.263 | 2.43 | 0.068 | 0.794 | 0.062 | 24.84 | 36.7 | 41.03 | 3.97 | 20.86 | 304.7 | 0.787 |
| 165 | 1992 | 8 | 227 | 33.1 | 5.459 | 2.480 | 0.284 | 2.42 | 0.068 | 0.806 | 0.070 | 22.75 | 38.3 | 41.88 | 3.32 | 19.44 | 306.3 | 0.794 |
| 166 | 1992 | 9 | 258 | 30.8 | 4.980 | 1.857 | 0.254 | 2.43 | 0.068 | 0.788 | 0.080 | 14.99 | 35.7 | 40.63 | 3.49 | 11.50 | 304.0 | 0.705 |
| 167 | 1992 | 10 | 288 | 24.6 | 3.460 | 1.466 | 0.185 | 2.44 | 0.068 | 0.731 | 0.091 | 14.79 | 31.9 | 37.39 | 4.98 | 9.81 | 297.7 | 0.603 |
| 168 | 1992 | 11 | 319 | 14.7 | 1.941 | 0.736 | 0.108 | 2.47 | 0.067 | 0.616 | 0.099 | 11.60 | 25.4 | 32.68 | 6.69 | 4.91 | 287.9 | 0.381 |
| 169 | 1992 | 12 | 349 | 9.7 | 1.337 | 0.822 | 0.081 | 2.48 | 0.067 | 0.547 | 0.102 | 8.82 | 24.1 | 30.45 | 5.11 | 3.71 | 282.8 | 0.377 |
| 170 | | | | | | | | | | | | | | | | | | |

| 172 EVAPORATION ESTIMATES: | | | | F | G | H | I | J | K | L | M | N | O | P | Q | R | S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 173 | | | | | | Penman (1963), (eo-ed) = f(Tavg) | | | | | Penman-Monteith (Smith, 1991): | | | | | | |
| 174 | | | | | | | | | | | | | | | | | |
| 175 | | | | f(Tavg) | | Aero term | | | | | | Rad | | Aero term | | | |
| 176 | | | | eo | Rad term | | Eo | Eo | Eo | g* | D/ | term | g/ | l | E | E | E |
| 177 Year | Mo | CD | Days/mo | kPa | MJ* | MJ* | MJ* | mm/d | In/mo | kPa/C | (D+g*) | MJ* | (D+g*) | MJ* | MJ* | mm/d | In/mo |
| 178 | | | | | | | | | | | | | | | | | |
| 179 1987 | 1 | 15 | 31 | 1.329 | 2.34 | 3.10 | 5.44 | 2.20 | 2.69 | 0.067 | 0.568 | 2.34 | 0.4318 | 2.63 | 4.97 | 2.01 | 2.45 |
| 180 1987 | 2 | 46 | 28 | 1.613 | 4.57 | 4.15 | 8.71 | 3.53 | 3.89 | 0.067 | 0.609 | 4.57 | 0.3913 | 3.54 | 8.10 | 3.28 | 3.62 |
| 181 1987 | 3 | 74 | 31 | 1.784 | 7.74 | 4.68 | 12.42 | 5.04 | 6.15 | 0.067 | 0.629 | 7.74 | 0.3709 | 4.10 | 11.84 | 4.81 | 5.87 |
| 182 1987 | 4 | 105 | 30 | 2.666 | 11.83 | 5.84 | 17.66 | 7.21 | 8.52 | 0.068 | 0.705 | 11.83 | 0.2945 | 4.75 | 16.58 | 6.77 | 7.99 |
| 183 1987 | 5 | 135 | 31 | 3.075 | 13.81 | 7.55 | 21.35 | 8.74 | 10.67 | 0.068 | 0.730 | 13.81 | 0.2697 | 6.05 | 19.86 | 8.13 | 9.92 |
| 184 1987 | 6 | 166 | 30 | 4.211 | 15.07 | 8.87 | 23.94 | 9.85 | 11.63 | 0.068 | 0.780 | 15.07 | 0.2202 | 6.74 | 21.80 | 8.97 | 10.59 |
| 185 1987 | 7 | 196 | 31 | 4.461 | 16.23 | 8.19 | 24.42 | 10.06 | 12.28 | 0.068 | 0.788 | 16.23 | 0.2119 | 6.14 | 22.37 | 9.21 | 11.24 |
| 186 1987 | 8 | 227 | 31 | 4.745 | 14.86 | 7.71 | 22.57 | 9.30 | 11.36 | 0.068 | 0.797 | 14.86 | 0.2032 | 5.75 | 20.61 | 8.50 | 10.37 |
| 187 1987 | 9 | 258 | 30 | 3.690 | 10.29 | 6.57 | 16.86 | 6.92 | 8.18 | 0.068 | 0.760 | 10.29 | 0.2402 | 5.06 | 15.35 | 6.30 | 7.44 |
| 188 1987 | 10 | 288 | 31 | 3.201 | 7.14 | 3.74 | 10.88 | 4.45 | 5.44 | 0.068 | 0.737 | 7.14 | 0.2630 | 2.79 | 9.93 | 4.07 | 4.97 |
| 189 1987 | 11 | 319 | 30 | 1.834 | 4.04 | 2.17 | 6.21 | 2.52 | 2.98 | 0.067 | 0.635 | 4.04 | 0.3654 | 1.70 | 5.73 | 2.33 | 2.75 |
| 190 1987 | 12 | 349 | 31 | 1.242 | 2.00 | 2.05 | 4.05 | 1.63 | 2.00 | 0.067 | 0.554 | 2.00 | 0.4462 | 1.74 | 3.73 | 1.51 | 1.84 |
| 191 1988 | 1 | 15 | 31 | 1.341 | 2.66 | 2.55 | 5.21 | 2.11 | 2.57 | 0.067 | 0.570 | 2.66 | 0.4299 | 2.24 | 4.89 | 1.98 | 2.41 |
| 192 1988 | 2 | 46 | 28 | 1.671 | 5.17 | 3.08 | 8.25 | 3.35 | 3.69 | 0.067 | 0.616 | 5.17 | 0.3841 | 2.70 | 7.87 | 3.19 | 3.52 |
| 193 1988 | 3 | 74 | 31 | 1.951 | 7.21 | 4.58 | 11.79 | 4.79 | 5.85 | 0.067 | 0.647 | 7.21 | 0.3531 | 4.00 | 11.21 | 4.56 | 5.56 |
| 194 1988 | 4 | 105 | 30 | 2.217 | 10.52 | 4.12 | 14.64 | 5.96 | 7.04 | 0.068 | 0.672 | 10.52 | 0.3284 | 3.58 | 14.10 | 5.74 | 6.78 |
| 195 1988 | 5 | 135 | 31 | 2.850 | 11.71 | 8.22 | 19.93 | 8.15 | 9.95 | 0.068 | 0.717 | 11.71 | 0.2827 | 7.27 | 18.98 | 7.76 | 9.47 |
| 196 1988 | 6 | 166 | 30 | 3.743 | 15.93 | 7.19 | 23.12 | 9.49 | 11.21 | 0.068 | 0.762 | 15.93 | 0.2379 | 5.70 | 21.63 | 8.88 | 10.49 |
| 197 1988 | 7 | 196 | 31 | 4.851 | 17.25 | 7.15 | 24.40 | 10.06 | 12.28 | 0.068 | 0.800 | 17.25 | 0.2002 | 5.42 | 22.67 | 9.35 | 11.41 |
| 198 1988 | 8 | 227 | 31 | 4.691 | 15.58 | 6.27 | 21.85 | 9.01 | 10.99 | 0.068 | 0.795 | 15.58 | 0.2048 | 4.51 | 20.09 | 8.28 | 10.10 |
| 199 1988 | 9 | 258 | 30 | 4.026 | 8.88 | 6.65 | 15.53 | 6.38 | 7.54 | 0.068 | 0.773 | 8.88 | 0.2268 | 4.90 | 13.78 | 5.66 | 6.69 |
| 200 1988 | 10 | 288 | 31 | 3.340 | 7.90 | 4.56 | 12.46 | 5.11 | 6.23 | 0.068 | 0.744 | 7.90 | 0.2560 | 3.36 | 11.27 | 4.62 | 5.64 |
| 201 1988 | 11 | 319 | 30 | 1.859 | 3.37 | 3.84 | 7.20 | 2.93 | 3.46 | 0.067 | 0.637 | 3.37 | 0.3627 | 3.14 | 6.51 | 2.64 | 3.12 |
| 202 1988 | 12 | 349 | 31 | 1.354 | 1.86 | 3.31 | 5.16 | 2.09 | 2.55 | 0.067 | 0.572 | 1.86 | 0.4279 | 2.83 | 4.69 | 1.89 | 2.31 |
| 203 1989 | 1 | 15 | 31 | 1.319 | 2.28 | 2.91 | 5.19 | 2.10 | 2.56 | 0.067 | 0.566 | 2.28 | 0.4335 | 2.42 | 4.71 | 1.90 | 2.32 |
| 204 1989 | 2 | 46 | 28 | 1.594 | 5.06 | 3.26 | 8.32 | 3.37 | 3.72 | 0.067 | 0.606 | 5.06 | 0.3939 | 2.96 | 8.02 | 3.25 | 3.58 |
| 205 1989 | 3 | 74 | 31 | 2.336 | 7.70 | 4.03 | 11.73 | 4.78 | 5.83 | 0.068 | 0.681 | 7.70 | 0.3186 | 3.53 | 11.23 | 4.58 | 5.59 |
| 206 1989 | 4 | 105 | 30 | 2.751 | 12.81 | 5.01 | 17.82 | 7.28 | 8.60 | 0.068 | 0.711 | 12.81 | 0.2889 | 4.17 | 16.98 | 6.94 | 8.19 |
| 207 1989 | 5 | 135 | 31 | 3.082 | 14.07 | 8.02 | 22.09 | 9.04 | 11.04 | 0.068 | 0.731 | 14.07 | 0.2694 | 6.69 | 20.76 | 8.50 | 10.37 |
| 208 1989 | 6 | 166 | 30 | 3.960 | 15.21 | 8.85 | 24.06 | 9.89 | 11.68 | 0.068 | 0.771 | 15.21 | 0.2293 | 7.14 | 22.35 | 9.19 | 10.85 |
| 209 1989 | 7 | 196 | 31 | 4.810 | 15.58 | 8.47 | 24.05 | 9.92 | 12.11 | 0.068 | 0.799 | 15.58 | 0.2013 | 6.39 | 21.97 | 9.06 | 11.06 |
| 210 1989 | 8 | 227 | 31 | 4.438 | 15.29 | 6.29 | 21.58 | 8.89 | 10.85 | 0.068 | 0.787 | 15.29 | 0.2126 | 4.71 | 19.99 | 8.23 | 10.05 |
| 211 1989 | 9 | 258 | 30 | 3.981 | 10.86 | 7.14 | 18.00 | 7.40 | 8.74 | 0.068 | 0.771 | 10.86 | 0.2285 | 5.42 | 16.28 | 6.69 | 7.90 |
| 212 1989 | 10 | 288 | 31 | 2.777 | 6.49 | 5.37 | 11.86 | 4.85 | 5.91 | 0.068 | 0.713 | 6.49 | 0.2873 | 4.14 | 10.62 | 4.34 | 5.30 |
| 213 1989 | 11 | 319 | 30 | 1.901 | 3.59 | 3.70 | 7.29 | 2.96 | 3.50 | 0.067 | 0.642 | 3.59 | 0.3582 | 3.08 | 6.67 | 2.71 | 3.20 |
| 214 1989 | 12 | 349 | 31 | 1.341 | 2.00 | 2.54 | 4.54 | 1.83 | 2.24 | 0.067 | 0.570 | 2.00 | 0.4300 | 2.23 | 4.23 | 1.71 | 2.09 |
| 215 1990 | 1 | 15 | 31 | 1.400 | 2.26 | 2.68 | 4.94 | 2.00 | 2.44 | 0.067 | 0.579 | 2.26 | 0.4209 | 2.42 | 4.68 | 1.89 | 2.31 |
| 216 1990 | 2 | 46 | 28 | 1.454 | 4.33 | 3.29 | 7.62 | 3.08 | 3.40 | 0.067 | 0.587 | 4.33 | 0.4130 | 3.03 | 7.37 | 2.98 | 3.29 |
| 217 1990 | 3 | 74 | 31 | 1.969 | 8.13 | 4.10 | 12.23 | 4.97 | 6.07 | 0.067 | 0.649 | 8.13 | 0.3513 | 3.65 | 11.78 | 4.79 | 5.84 |
| 218 1990 | 4 | 105 | 30 | 2.466 | 9.97 | 4.19 | 14.16 | 5.78 | 6.82 | 0.068 | 0.691 | 9.97 | 0.3086 | 3.47 | 13.44 | 5.48 | 6.47 |
| 219 1990 | 5 | 135 | 31 | 2.846 | 13.34 | 7.50 | 20.84 | 8.52 | 10.40 | 0.068 | 0.717 | 13.34 | 0.2830 | 6.29 | 19.63 | 8.02 | 9.79 |
| 220 1990 | 6 | 166 | 30 | 3.966 | 15.28 | 7.01 | 22.30 | 9.16 | 10.82 | 0.068 | 0.771 | 15.28 | 0.2291 | 5.32 | 20.61 | 8.47 | 10.00 |
| 221 1990 | 7 | 196 | 31 | 4.780 | 14.77 | 7.38 | 22.15 | 9.13 | 11.15 | 0.068 | 0.798 | 14.77 | 0.2022 | 5.44 | 20.21 | 8.33 | 10.17 |
| 222 1990 | 8 | 227 | 31 | 4.338 | 10.62 | 5.45 | 16.06 | 6.61 | 8.07 | 0.068 | 0.784 | 10.62 | 0.2159 | 3.80 | 14.42 | 5.94 | 7.24 |
| 223 1990 | 9 | 258 | 30 | 4.003 | 12.44 | 4.91 | 17.35 | 7.13 | 8.42 | 0.068 | 0.772 | 12.44 | 0.2277 | 3.52 | 15.96 | 6.56 | 7.75 |
| 224 1990 | 10 | 288 | 31 | 2.800 | 7.38 | 4.18 | 11.56 | 4.73 | 5.77 | 0.068 | 0.714 | 7.38 | 0.2858 | 3.07 | 10.45 | 4.27 | 5.21 |
| 225 1990 | 11 | 319 | 30 | 1.825 | 2.49 | 4.17 | 6.67 | 2.71 | 3.20 | 0.067 | 0.634 | 2.49 | 0.3664 | 3.27 | 5.76 | 2.34 | 2.76 |

| | Year | Mo | DOY | Days | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 226 | 1990 | 12 | 349 | 31 | 1.246 | 1.48 | 3.25 | 4.74 | 1.91 | 2.33 | 0.067 | 0.554 | 1.48 | 0.4456 | 2.64 | 4.12 | 1.66 | 2.03 |
| 227 | 1991 | 1 | 15 | 31 | 1.372 | 1.88 | 2.59 | 4.47 | 1.81 | 2.21 | 0.067 | 0.575 | 1.88 | 0.4252 | 1.94 | 3.82 | 1.55 | 1.89 |
| 228 | 1991 | 2 | 46 | 28 | 1.808 | 5.15 | 2.66 | 7.81 | 3.17 | 3.50 | 0.067 | 0.632 | 5.15 | 0.3683 | 2.31 | 7.46 | 3.03 | 3.34 |
| 229 | 1991 | 3 | 74 | 31 | 1.618 | 7.14 | 3.29 | 10.43 | 4.23 | 5.16 | 0.067 | 0.609 | 7.14 | 0.3907 | 2.86 | 10.00 | 4.05 | 4.95 |
| 230 | 1991 | 4 | 105 | 30 | 2.154 | 11.45 | 4.33 | 15.78 | 6.42 | 7.59 | 0.068 | 0.666 | 11.45 | 0.3339 | 3.83 | 15.28 | 6.22 | 7.35 |
| 231 | 1991 | 5 | 135 | 31 | 2.613 | 14.92 | 5.06 | 19.99 | 8.16 | 9.96 | 0.068 | 0.702 | 14.92 | 0.2981 | 4.39 | 19.31 | 7.89 | 9.62 |
| 232 | 1991 | 6 | 166 | 30 | 3.410 | 13.53 | 5.65 | 19.18 | 7.86 | 9.29 | 0.068 | 0.747 | 13.53 | 0.2526 | 4.44 | 17.96 | 7.36 | 8.70 |
| 233 | 1991 | 7 | 196 | 31 | 4.244 | 16.65 | 5.53 | 22.17 | 9.12 | 11.14 | 0.068 | 0.781 | 16.65 | 0.2190 | 4.08 | 20.73 | 8.53 | 10.41 |
| 234 | 1991 | 8 | 227 | 31 | 4.634 | 15.16 | 6.19 | 21.34 | 8.80 | 10.74 | 0.068 | 0.793 | 15.16 | 0.2065 | 4.37 | 19.53 | 8.05 | 9.82 |
| 235 | 1991 | 9 | 258 | 30 | 4.118 | 11.65 | 4.92 | 16.57 | 6.81 | 8.05 | 0.068 | 0.776 | 11.65 | 0.2235 | 3.47 | 15.12 | 6.22 | 7.35 |
| 236 | 1991 | 10 | 288 | 31 | 3.159 | 7.29 | 5.05 | 12.34 | 5.05 | 6.17 | 0.068 | 0.735 | 7.29 | 0.2652 | 3.88 | 11.16 | 4.57 | 5.58 |
| 237 | 1991 | 11 | 319 | 30 | 1.886 | 2.21 | 5.06 | 7.27 | 2.95 | 3.49 | 0.067 | 0.640 | 2.21 | 0.3598 | 3.90 | 6.11 | 2.48 | 2.93 |
| 238 | 1991 | 12 | 349 | 31 | 1.425 | 2.08 | 1.95 | 4.02 | 1.63 | 1.99 | 0.067 | 0.583 | 2.08 | 0.4171 | 1.42 | 3.50 | 1.41 | 1.73 |
| 239 | 1992 | 1 | 15 | 31 | 1.376 | 2.54 | 2.34 | 4.87 | 1.97 | 2.40 | 0.067 | 0.575 | 2.54 | 0.4246 | 1.86 | 4.39 | 1.78 | 2.17 |
| 240 | 1992 | 2 | 46 | 28 | 1.759 | 4.97 | 2.47 | 7.44 | 3.02 | 3.33 | 0.067 | 0.626 | 4.97 | 0.3737 | 1.98 | 6.95 | 2.82 | 3.11 |
| 241 | 1992 | 3 | 74 | 31 | 1.827 | 7.57 | 1.90 | 9.47 | 3.85 | 4.69 | 0.067 | 0.634 | 7.57 | 0.3661 | 1.57 | 9.13 | 3.71 | 4.53 |
| 242 | 1992 | 4 | 105 | 30 | 2.623 | 10.34 | 3.43 | 13.76 | 5.62 | 6.64 | 0.068 | 0.703 | 10.34 | 0.2974 | 2.62 | 12.95 | 5.29 | 6.25 |
| 243 | 1992 | 5 | 135 | 31 | 3.213 | 14.91 | 4.21 | 19.12 | 7.83 | 9.56 | 0.068 | 0.738 | 14.91 | 0.2624 | 3.17 | 18.08 | 7.41 | 9.04 |
| 244 | 1992 | 6 | 166 | 30 | 3.726 | 15.30 | 5.56 | 20.85 | 8.56 | 10.11 | 0.068 | 0.761 | 15.30 | 0.2386 | 4.37 | 19.67 | 8.07 | 9.54 |
| 245 | 1992 | 7 | 196 | 31 | 4.639 | 16.56 | 6.19 | 22.75 | 9.37 | 11.44 | 0.068 | 0.794 | 16.56 | 0.2063 | 4.51 | 21.07 | 8.68 | 10.60 |
| 246 | 1992 | 8 | 227 | 31 | 5.068 | 15.66 | 6.29 | 21.95 | 9.06 | 11.06 | 0.068 | 0.806 | 15.66 | 0.1943 | 4.54 | 20.20 | 8.34 | 10.17 |
| 247 | 1992 | 9 | 258 | 30 | 4.449 | 9.06 | 5.59 | 14.64 | 6.03 | 7.12 | 0.068 | 0.788 | 9.06 | 0.2122 | 3.92 | 12.97 | 5.34 | 6.31 |
| 248 | 1992 | 10 | 288 | 31 | 3.089 | 7.17 | 4.38 | 11.55 | 4.73 | 5.77 | 0.068 | 0.731 | 7.17 | 0.2690 | 3.20 | 10.37 | 4.24 | 5.18 |
| 249 | 1992 | 11 | 319 | 30 | 1.674 | 3.02 | 3.59 | 6.62 | 2.68 | 3.17 | 0.067 | 0.616 | 3.02 | 0.3838 | 2.86 | 5.88 | 2.39 | 2.82 |
| 250 | 1992 | 12 | 349 | 31 | 1.202 | 2.03 | 1.63 | 3.65 | 1.47 | 1.80 | 0.067 | 0.547 | 2.03 | 0.4533 | 1.35 | 3.38 | 1.37 | 1.67 |

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| 252 | SUMMARY OF EVAPORATION ESTIMATES: | | Penman Eo: | | | | | Priestley-Taylor: | | Penman-Monteith:zo= 2E-04 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 253 | | CIMIS-41, Mulberry | Rad term | Aero | | Eo | | | | | Rad term | Aero | E | |
| 254 | Year | Styles CIMIS, ETo | Inches | Inches | Inches | Pct | | Inches | Pct | Inches | Inches | Inches | Pct |
| 255 | ------- | ------- | ------- | | ------------- | | | ------------- | | ------- | | ------------- | |
| 256 | 1987 | 82.8 | 112.6% | 53.0 | 31.1 | 85.8 | 104.8% | 68.1 | 101.5% | 53.0 | 24.6 | 79.1 | 104.3% |
| 257 | 1988 | 77.7 | 105.6% | 52.1 | 29.7 | 83.4 | 101.8% | 67.0 | 99.8% | 52.1 | 23.9 | 77.5 | 102.2% |
| 258 | 1989 | 75.1 | 102.1% | 53.5 | 31.6 | 86.8 | 106.0% | 68.7 | 102.4% | 53.5 | 25.5 | 80.5 | 106.2% |
| 259 | 1990 | 72.1 | 98.0% | 49.4 | 28.0 | 78.9 | 96.4% | 63.5 | 94.6% | 49.4 | 22.1 | 72.9 | 96.1% |
| 260 | 1991 | 67.8 | 92.2% | 52.6 | 25.2 | 79.3 | 96.8% | 67.6 | 100.7% | 52.6 | 19.7 | 73.7 | 97.1% |
| 261 | 1992 | 65.8 | 89.5% | 52.6 | 22.9 | 77.1 | 94.2% | 67.7 | 100.9% | 52.6 | 17.3 | 71.4 | 94.1% |
| 262 | | ------------- | | ------------------------- | | | ------------- | | | ------------------------- | | | |
| 263 | Average | 73.6 | 100.0% | 52.2 | 28.1 | 81.9 | 100.0% | 67.1 | 100.0% | 52.2 | 22.2 | 75.8 | 100.0% |
| 264 | | | | 65.0% | 35.0% | | 73.7 Lake E | | 1.02USGS: | | 70.2% | 29.8% | 75.8 Lake E |

| 265 | Month | CIMIS Eto | CM/USGS | P-ETo: In/mo | PETo/GSPen | Eo: In/mo | Px0.9/USGS | In/mo | | P-M: In/mo | PM/GS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 266 | Jan | 2.62 | 1.36 | 2.74 | 1.42 | 2.48 | 1.16 | 1.92 | | 2.26 | 1.18 |
| 267 | Feb | 3.49 | 1.26 | 3.58 | 1.29 | 3.59 | 1.16 | 2.78 | | 3.41 | 1.23 |
| 268 | Mar | 5.35 | 1.20 | 5.40 | 1.21 | 5.63 | 1.13 | 4.46 | | 5.39 | 1.21 |
| 269 | Apr | 7.04 | 1.09 | 6.98 | 1.08 | 7.53 | 1.05 | 6.44 | | 7.17 | 1.11 |
| 270 | May | 9.00 | 0.96 | 9.28 | 0.99 | 10.26 | 0.99 | 9.34 | | 9.70 | 1.04 |
| 271 | Jun | 9.43 | 1.20 | 9.46 | 1.20 | 10.79 | 1.23 | 7.87 | | 10.03 | 1.27 |
| 272 | Jul | 9.50 | 1.08 | 10.14 | 1.15 | 11.73 | 1.20 | 8.82 | | 10.82 | 1.23 |
| 273 | Aug | 8.84 | 0.92 | 9.44 | 0.99 | 10.51 | 0.99 | 9.55 | | 9.63 | 1.01 |
| 274 | Sep | 7.32 | 0.85 | 7.74 | 0.90 | 8.01 | 0.84 | 8.61 | | 7.24 | 0.84 |
| 275 | Oct | 5.11 | 0.72 | 5.87 | 0.83 | 5.88 | 0.75 | 7.07 | | 5.31 | 0.75 |
| 276 | Nov | 3.46 | 0.82 | 3.61 | 0.86 | 3.30 | 0.71 | 4.20 | | 2.93 | 0.70 |
| 277 | Dec | 2.34 | 1.08 | 2.42 | 1.12 | 2.15 | 0.90 | 2.16 | | 1.94 | 0.90 |
| 278 | Total | 73.5 | 1.00 | 76.7 | 1.05 | 81.9 | 1.01 | 73.2 | | 75.8 | 1.04 |

# APPENDIX 6

## EVAPOTRANSPIRATION AND ON-FARM CONSUMPTIVE USE ESTIMATES FOR IID

# APPENDIX 6

## EVAPOTRANSPIRATION AND ON-FARM CONSUMPTIVE USE ESTIMATES FOR IID

by
Marvin E. Jensen
21 November 1993

### INTRODUCTION

The Technical Work Group (TWG) is using several approaches to estimating farm irrigation efficiency. One approach is to estimate evapotranspiration (ET) for major crop groups and then multiply the ET by crop acreages to arrive at total ET. Estimating ET for the numerous crops grown in the Imperial Irrigation District (IID) required summarizing extensive climatic data and selecting and adapting crop coefficient values for convenient use on a daily basis using a spreadsheet approach. In hindsight, writing a separate software program may have been more efficient. For future routine computations, a software program in BASIC or FORTRAN should be considered.

The major input variable used in this analysis was the reference ET ($ET_o$) values provided by the three CIMIS stations (41, 68 and 87) in the valley. Disk file copies (UPDATE.DBF and UPDATE1.DBF) of CIMIS data used in preparing the summary data in the Boyle/Styles (1993) report were used in this study as was done for evaluating reference ET estimates.

The procedures developed and used in this analysis will be used in making similar estimates for the Coachella Valley Water District.

### PROCEDURES

#### Alternative Mean Climate Data Sets

Six years of daily $ET_o$ values were available from CIMIS station 41 (Mulberry), five years from Station 68 (Seeley), and three years from Station 87 (Meloland) for the period 1987-1992. If daily estimates for individual years were to be used a matrix of 2192 rows would have been required and numerous repetitive applications of crop coefficients adjusted for individual years would have been required. A spreadsheet approach would have been very cumbersome and the resulting spreadsheet would have been very large.

The alternative approach of establishing a set of mean daily $ET_o$ for 365 days based on the data available from the three CIMIS stes was selected. First, mean daily reference ET values was calculated for each of the three stations. Then, the mean daily

values of ET for the three stations were calculated. Even with this reduced matrix, a computer software that enabled using expanded memory was required when estimating ET for individual crops and converting and saving individual crop values. Four sets of spreadsheets were used to enable estimating and saving ET values for all of the crops.

### Crop Coefficient Data Sets

Two primary sources of crop coefficients ($K_c$) were evaluated before selecting coefficients for various crops: 1) University of California Leaflet 21427, and 2) a set coefficients provided by JMLord, Inc. The ASCE Manual 70 and several other references provided alternative values for some crops. Leaflet 21427 (UC, undated) provided starting point information about planting and harvest dates for many crops grown in the IID.

After extensive development of daily coefficients for use in making daily estimates of ET, I was **not** able to use these values in quantifying ET values for most crops because the values clearly do not represent real crop development characteristics as will be illustrated later. **The UC coefficients appear to be intended for management purposes such as irrigation scheduling and possibly for establishing peak ET values for determining system capacity requirements. They do not appear adequate for estimating the quantity of ET.**

The data set provided by JMLord, Inc. has five values for the growth period from planting to full cover (0, 25, 50, 75, and 100 %), and four values for growth periods after full cover (growth intervals 1, 2, 3 and 4). Applying these coefficient on a daily basis would have required interpolation between two data points for seven periods for each crop. This would have been very cumbersome using a spreadsheet approach. Therefore, generic equations for daily values were calibrated for the two periods, 1-100 percent of full cover and days after full cover. This required only two equations for each crop instead of seven. The generic equation was based on curves of crop coefficients that were developed from daily lysimeter data for row crops and close-planted crops by Wright as summarized in ASCE Manual 70 (Jensen et al., 1990).

Since the JMLord crop coefficients are for use with an alfalfa reference crop, the daily coefficients were multiplied by 1.2 for use with CIMIS reference ET.

### Rainfall Values for the Mean Climatic Data Set

Rainfall data from the three CIMIS stations were summarized and grouped into discrete rainfall events for each month of the year. Then, based on the average number of rain storms of different

sizes, a set of monthly rain storms was selected to provide approximately the same average total annual rainfall for the 1987-1992 period. With these average rainfall events, an estimate of effective rainfall for each crop could be obtained.

### Effective Rainfall

Since almost all of the individual rainfall events were very small, no runoff was assumed and the increase in evaporation following a rain event was based on the following equations (ASCE Manual 70, page 118):

$$E+ = 0.35(1.5 + t_d)(K_1 - K_a K_{cb})ET_o \tag{1}$$

where $E+$ = the increase in evaporation following wetting of the soil and foliage, $t_d$ is the number of days for the soil surface to visually appear dry (7 days was used for a fine texture soil), $K_1$ is the maximum value of $K_c$ after a rain or irrigation (1.2 was used), $K_{cb}$ is the basal crop coefficient, and $K_a$ is a dimensionless coefficient that is dependent on available soil water ( $K_a$ = 1.0, soil water not limiting, for this analysis). The maximum value of $E+$ could not exceed the rainfall received.

### Major Crop Groupings

A very large number of crops are grown in the IID, but many represent a very small percentage of the irrigated crop land. Therefore, a six-year summary of crops was used to select the major crops for which estimated ET was needed. Then, the average crop acreages were used to estimate the total ET for the average 1987-1992 period.

### Cropping Period for ET Estimates

Estimates of ET were made from planting to harvest. Soil water was assumed to be at the drained upper limit, or field capacity, at planting for a fine texture soil (ASCE Manual 70, page 21). Since no information was available on irrigation frequency or rooting depth, available soil water was not assumed to affect ET except as later adjusted for alfalfa.

### Evaporation Losses after Preplant-Irrigations

Since ET estimates were desired, no estimates of evaporation losses during and after preplant-irrigations were included in my estimates. Assuming that preplant-irrigations were made prior to planting or for germinating seeds, evaporation estimates can be made. **Estimates of evaporation after both pre-plant irrigations and irrigations during the growing season would need to be added when comparing water balance estimates with crop ET estimates.**

### Variable or Partial Harvest

Since sugar beets are not harvested and stored for processing as is done in northern states, harvesting of sugar beets was assumed to begin two months before the final harvest date for each of the two planting dates. The total ET was reduced by the average ET for the last two months. This basically assumes that the area of growing beets was reduced linearly for the last 60 days of each growing period.

### Adjusting ET Estimates for Alfalfa

It is well established that it is difficult to apply sufficient water to alfalfa in the IID to provide leaching, or even to avoid crop water stress and reduced ET rates. The TWG agreed that consideration should be given to average alfalfa hay yields in the IID in estimating alfalfa ET. Therefore, several data sets were selected from the literature to assess crop yield v. ET relationships. Since most of the relationships found in the literature were based on dry matter (DM) production (zero moisture), all values used were first converted to DM, if not reported as such, and then a linear regression equation was derived. The equation was then adjusted to represent alfalfa hay at 12 percent moisture and cubed and dehydrated alfalfa (0% moisture). The units were than converted to units of tons per acre and inches of annual ET. Alfalfa yields for the years 1987-1992 were than averaged and the linear yield-ET equation was applied to estimate alfalfa ET.

### Evaporation Estimates for Duck Ponds, Fish Farms & Leaching

Average evaporation estimates for ponds and reservoirs in my report "Evaluating Evaporation Estimates for IID" were used for duck ponds, fish farms and for areas being leached. It was assumed that areas being leached remained flooded for at least a month. Therefore, 1/10 of annual pond evaporation was used for estimates of evaporation during leaching.

### Total ET and On-Farm Irrigation Efficiency

Total ET was obtained by multiplying ET by the average crop acreage obtained from the Boyle (1993) report. The consumptive use coefficient, $C_{cu}$, was estimated by dividing the total ET by total water delivered as reported in the Boyle report. The on-farm irrigation efficiency was estimated by including an average leaching requirement of 0.12.

# INTERMEDIATE RESULTS OF PROCEDURES

## Mean Reference ET Data Set

Mean daily reference ET from CIMIS data from the three sites is presented in Fig. 1. Averaging the three stations narrowed the daily variations, but they still existed. A moving five-day mean would have eliminated much of the daily variability. Of interest is the dip in reference ET values during May-June. The USGS Salton Sea study (Hely et al., 1966) showed similar reduced values during this period.

## Mean Annual Rainfall Distribution Data Set

An analysis of rainfall events for the three stations is summarized in Table 1. For the average 1987-1992 year, the number of rainfall events and amounts are summarized in Table 2. Based on the frequency of rainfall events, 80 percent falls in the range of 0 - 0.25 inch, 16 percent in 0.26-0.50 inch, and 3 percent in 0.51-0.75 inch. Only 1 percent resulted in more than 0.75 inch. The average rainfall for the period was 4.88 inches.

Table 1. Average number of annual rainfall events in each of nine ranges of amounts.

| Month | 0-0.25 | 0.26-0.50 | 0.51-0.75 | 0.76-1.00 | 1.01-1.25 | 1.26-1.50 | 1.51-1.75 | 1.76-2.00 | 2.01-2.25 | 2.26-2.50 |
|-------|--------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| | | | | | Range, inches | | | | | |
| Jan | 2.6 | 0.6 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Feb | 1.7 | 0.6 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mar | 2.9 | 0.1 | 0.3 | 0 | 0.1 | 0 | 0 | 0 | 0.1 | 0.1 |
| Apr | 0.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| May | 1.1 | 0.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Jun | 1.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Jul | 1.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Aug | 2.1 | 0.1 | 0.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sep | 1.0 | 0.3 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Oct | 1.4 | 0.3 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nov | 1.4 | 0.1 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Dec | 6.5 | 2.7 | 0.8 | 0.1 | 0.1 | 0 | 0 | 0 | 0 | 0 |

## Crops and Cropping Periods

The major crops and the estimated periods of growth used for these estimates are summarized in Table 3. The acres of each crop are summarized in a later table. Most of the dates were obtained from UC Leaflet 21427.

# AVERAGE REFERENCE ET - IID

## CIMIS STATIONS 41, 68 & 87 -- 1987-92
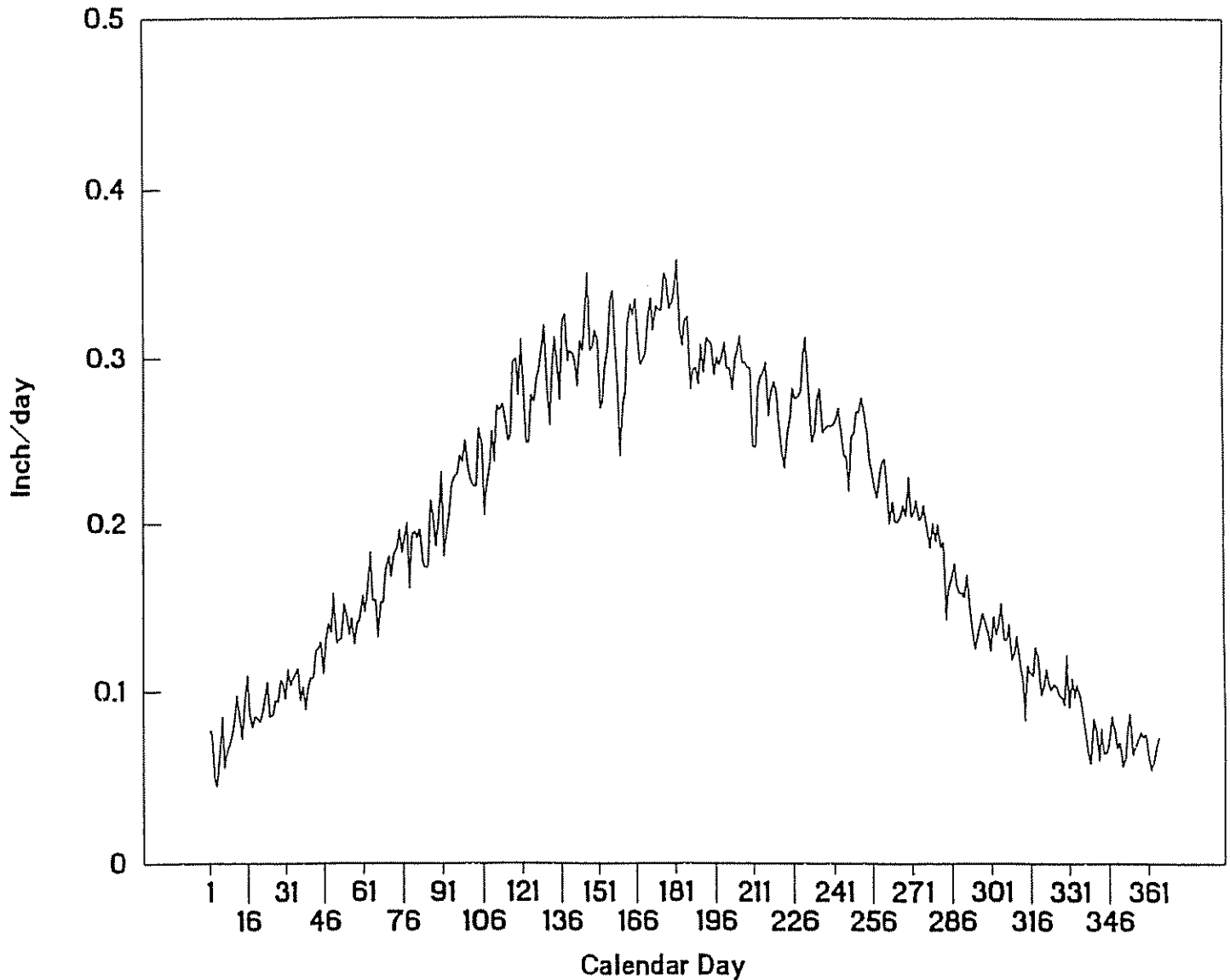


Figure 1. Mean daily ET from CIMIS Stations 41 (Mulberry), 68 (Seeley) and 87 (Meloland).

Table 2. Number of rainfall events and amounts used for the average 1987-1992 year in each of nine ranges of amounts.

| Month | 0- 0.25 | 0.26- 0.50 | 0.51- 0.75 | 0.76- 1.00 | 1.01- 1.25 | 1.26- 1.50 | 1.51- 1.75 | 1.76- 2.00 | 2.01- 2.25 | Total |
|-------|------|------|------|------|------|------|------|------|------|-------|
| Jan | 2 | 1 | | | | | | | | 3 |
| Feb | 2 | 0 | 1 | | | | | | | 3 |
| Mar | 3 | | | | | | | | | 3 |
| Apr | 1 | | | | | | | | | 1 |
| May | 1 | | | | | | | | | 1 |
| Jun | 1 | | | | | | | | | 1 |
| Jul | 1 | | | | | | | | | 1 |
| Aug | 2 | | | | | | | | | 2 |
| Sep | 1 | | | | | | | | | 1 |
| Oct | 1 | 1 | | | | | | | | 2 |
| Nov | 2 | | | | | | | | | 2 |
| Dec | 3 | 1 | | | | | | | | 4 |
| Total | 20 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 24 |
| Rain | 2.50 | 1.13 | 0.63 | 0 | 0 | 0 | 0 | 0 | 0 | 4.25 |

Range, inches

## Crop Coefficients

University of California Crop Coefficients. Daily UC crop coefficient values were first calculated for individual days for the growth periods in Table 3. Sets of UC coefficients are shown in Figures 2 and 3. What is immediately apparent is that changes in the coefficients for crop growth are represented by the straight lines. The impact of these values in estimating the **quantity** of water consumed in ET was not apparent until they were compared with other coefficients for a crop like barley such as those by JMLord and Wright multiplied by 1.2 (Fig. 4).

JMLord, Inc. Coefficients. Crop coefficients after plant emergence increase with plant growth or leaf area. The rate of leaf area development typically increases as a function of leaf area as illustrated in Figures 5 for the period before full cover and ET and the crop coefficient decrease with maturity as illustrated in Figure 6 for days after full cover. The values in Figures 5 and 6 were based on daily crop coefficient values determined using lysimeter measurements of ET. The curves in the figures are of an exponential or power function type for use with alfalfa as the reference crop. For example, the average equation for row crops (sugar beets, potatoes, corn and beans) illustrated in Figure 5 is:

$$K_{cb} = 0.15 \frac{(P - 30)^{1.8}}{2650} \ , for \ 30 < P < 100 \tag{2}$$

Table 3. Summary of major crops, growth periods dates, days between planting and full cover, and days between full cover and harvest for IID as used in estimating ET. For Phase II, some refinement is needed in dates which will require assessment of average planting dates, leaf area development rates and harvest dates.

| Row | 24-Feb-94 | SUMMARY OF CROP GROWTH PERIODS AND DAYS TO FULL COVER | | | | | | | | \CROP-PER |
|---|---|---|---|---|---|---|---|---|---|---|
| 19 | ================================================================================================= | | | | | | | | | |
| 20 | | Start or plant | | Full cover | | Harvest | | | Days | |
| 21 | | ---------------- | | --------------- | | --------------- | | ------------------------ | | |
| 22 | Crop | Date | CD | Date | CD | Date | CD | Plt-FC | FC-Harv | Plt-Harv |
| 23 | ------------------------------------------------------------------------------------------------- | | | | | | | | | |
| 24 | FIELD: | | | | | | | | | |
| 25 | Alfalfa, 6/15-7/15 * | 15-Jun | 166 | 07-Jul | 188 | | 196 | 22 | 8 | 30 |
| 26 | Alfalfa Seed | 15-Mar | 74 | - - | - - | 01-Aug | 213 | - - | - - | 140 |
| 27 | Bermuda Grass | 01-Mar | 60 | - - | - - | 01-Oct | 274 | - - | - - | 215 |
| 28 | Cotton | 31-Mar | 90 | 12-Aug | 224 | 31-Oct | 304 | 134 | 80 | 215 |
| 29 | Oats | 01-Jan | 1 | 05-Mar | 64 | 30-Apr | 120 | 63 | 56 | 120 |
| 30 | Rye Grass | 01-Jan | 1 | - - | - - | 30-Apr | 120 | - - | 120 | 120 |
| 31 | Sudan Grass | 01-Apr | 91 | 24-May | 144 | 01-Oct | 274 | - - | 130 | 184 |
| 32 | Sugar Beets-1 | 30-Jun | 181 | 09-Feb | 405 | 30-Apr | 485 | 224 | 80 | 305 |
| 33 | Sugar Beets-2 | 30-Sep | 273 | 10-Feb | 406 | 30-Jun | 546 | 133 | 140 | 274 |
| 34 | Wheat | 01-Jan | 1 | 24-Mar | 81 | 31-May | 151 | 80 | 70 | 151 |
| 35 | | | | | | | | | | |
| 36 | FRUIT: | | | | | | | | | |
| 37 | Citrus | 01-Jan | 1 | - - | - - | 31-Dec | 365 | - - | - - | 365 |
| 38 | Peaches/Pecans | 01-Apr | 91 | - - | - - | 16-Nov | 320 | - - | - - | 230 |
| 39 | | | | | | | | | | |
| 40 | TRUCK: | | | | | | | | | |
| 41 | Artichoke | 01-May | 121 | - - | - - | 10-Mar | 434 | - - | - - | 314 |
| 42 | Asparagus | 01-Jan | 1 | - - | - - | 31-Dec | 365 | - - | - - | 365 |
| 43 | Brocolli | 15-Sep | 258 | 17-Dec | 351 | 15-Feb | 411 | 93 | 60 | 154 |
| 44 | Cantaloupe-1 | 31-Jan | 31 | 12-Mar | 71 | 31-May | 151 | 40 | 80 | 121 |
| 45 | Cantaloupe-2 | 31-Jul | 212 | 12-Oct | 285 | 31-Dec | 365 | 73 | 80 | 154 |
| 46 | Carrots | 30-Sep | 273 | 09-Feb | 405 | 30-Apr | 485 | 132 | 80 | 213 |
| 47 | Cauliflower | 01-Oct | 274 | - - | - - | 31-Jan | 396 | - - | - - | 123 |
| 48 | Corn, sweet | 15-Jan | 15 | 24-Feb | 55 | 15-May | 135 | 40 | 80 | 121 |
| 49 | Lettuce-1 | 31-Aug | 243 | 24-Sep | 267 | 02-Jan | 367 | 24 | 100 | 125 |
| 50 | Lettuce-2 | 31-Oct | 304 | 21-Dec | 355 | 31-Mar | 455 | 51 | 100 | 152 |
| 51 | Melons, Honeydew, F | 01-Aug | 213 | 12-Oct | 285 | 31-Dec | 365 | 72 | 80 | 153 |
| 52 | Melons, Water | 01-Aug | 213 | 12-Oct | 285 | 31-Dec | 365 | 72 | 80 | 153 |
| 53 | Onions | 31-Dec | 365 | 20-Feb | 416 | 31-May | 516 | 51 | 100 | 152 |
| 54 | Onion Seed | 31-Dec | 365 | 20-Feb | 416 | 31-May | 516 | 51 | 100 | 152 |
| 55 | Tomatoes, Spring | 31-Jan | 31 | 11-Apr | 101 | 30-Jun | 181 | 70 | 80 | 151 |
| 56 | ------------------------------------------------------------------------------------------------- | | | | | | | | | |
| 57 | * Other cutting dates are: 8/15; 9/15; 11/15; 01/15; 03/15; 04/15; and 05/15. | | | | | | | | | |

# CROP COEFFICENTS - IID
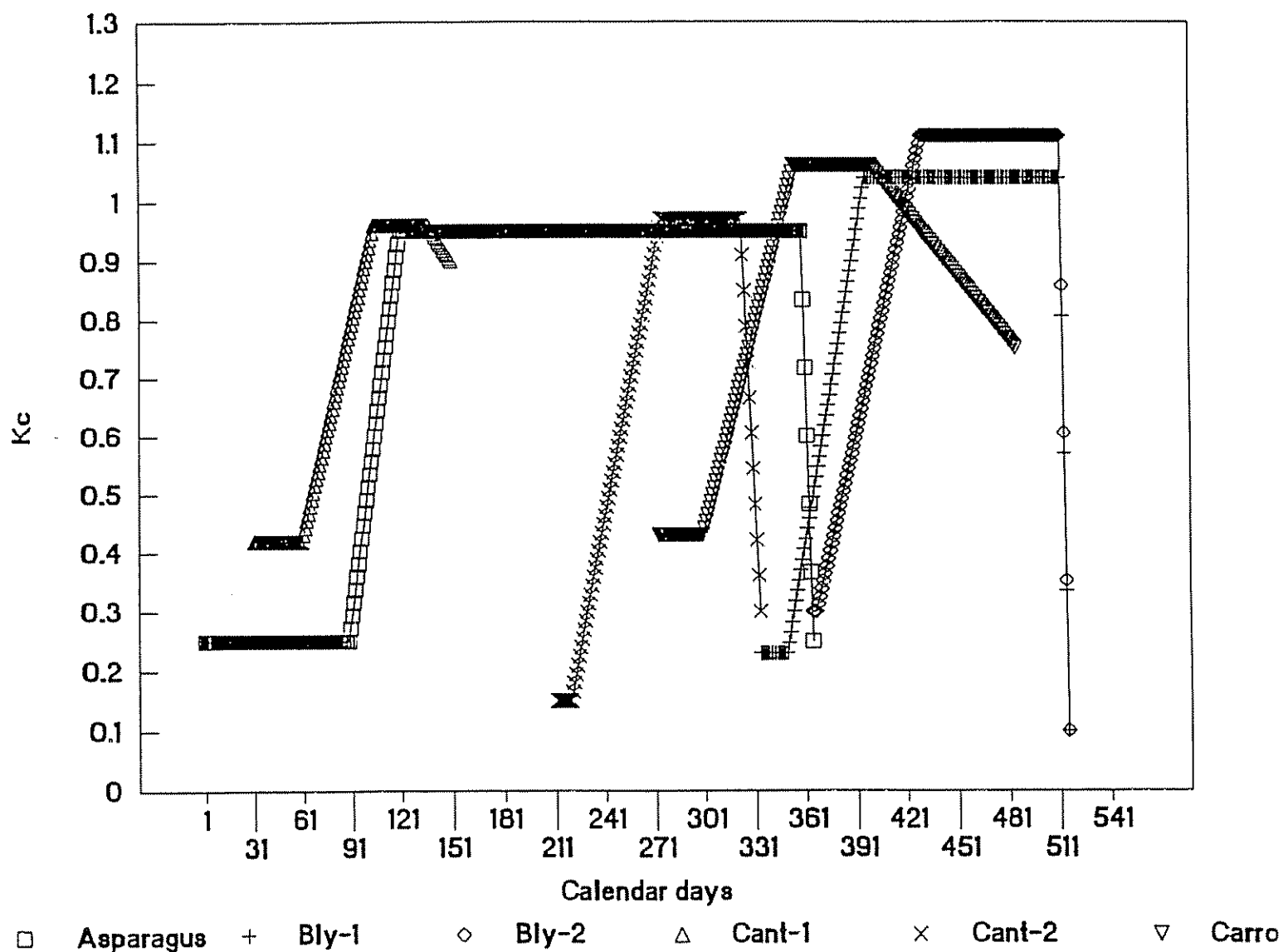
## U of C. L-21427



Figure 2. Daily crop coefficients for asparagus, two dates of barley plantings, two dates of cantaloupe plantings and carrots (Calculated from UC Leaflet 21427).

# CROP COEFFICENTS - IID

## U of C, L-21427
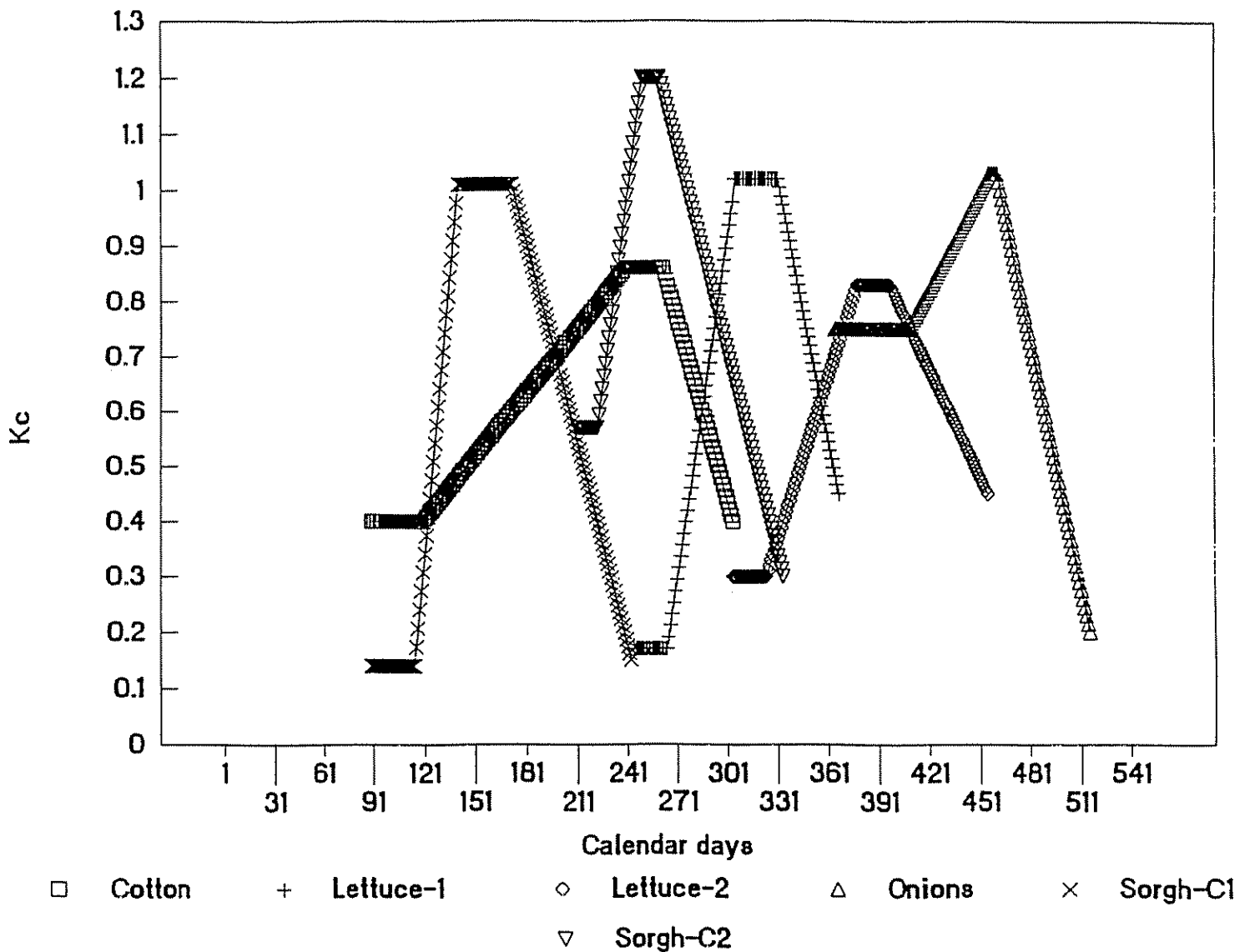


Figure 3. Daily crop coefficients for cotton, two dates of lettuce plantings, onions, and two dates of sorghum cuttings (Calculated from UC Leaflet 21427).

# CROP COEFFICIENTS - IID

## JML Kc x 1.2 v. UC Kc
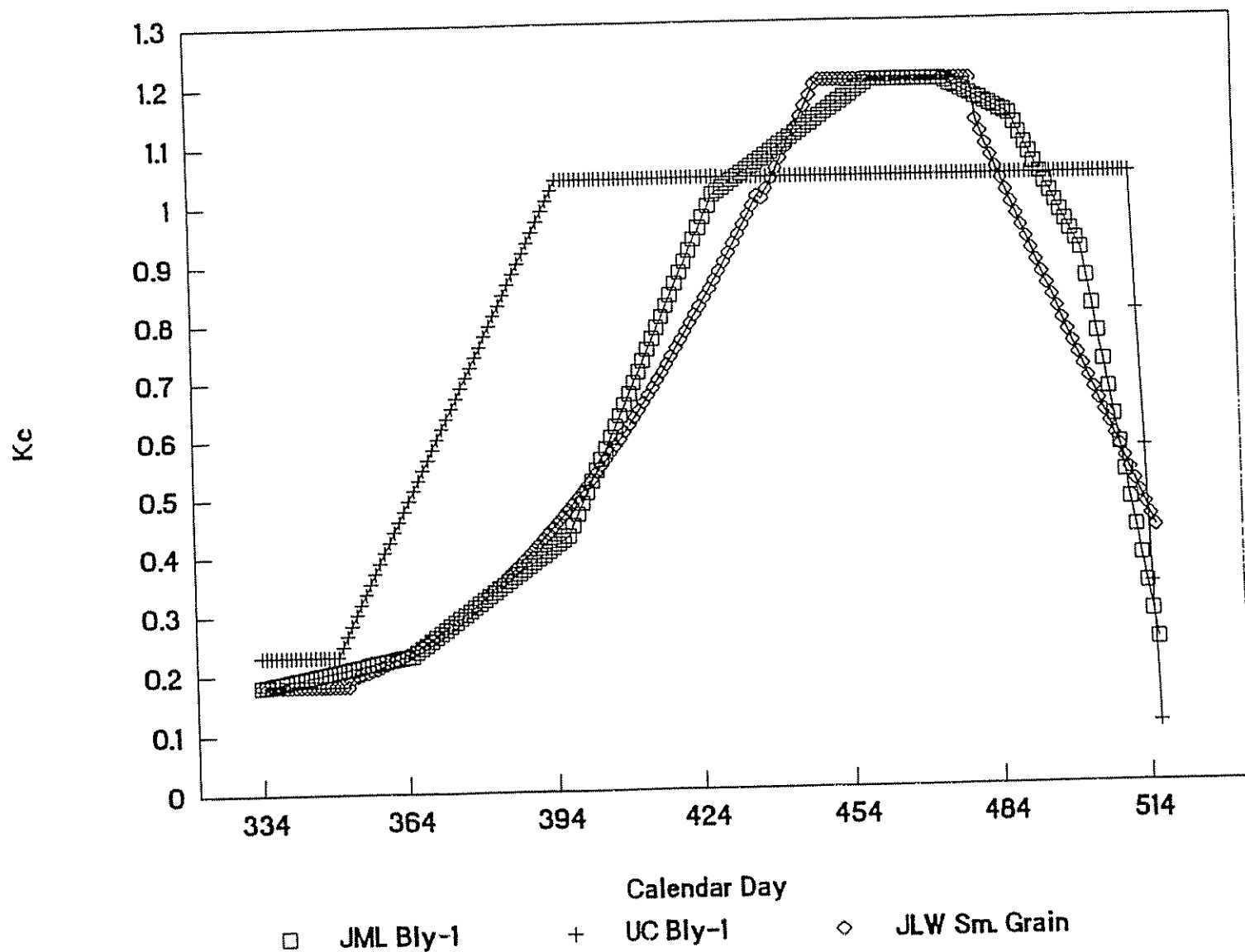


Figure 4. Comparison of UC, JMLord, and Wright's daily crop coefficients for barley.

# J L WRIGHT'S BASAL CROP COEFFICENTS
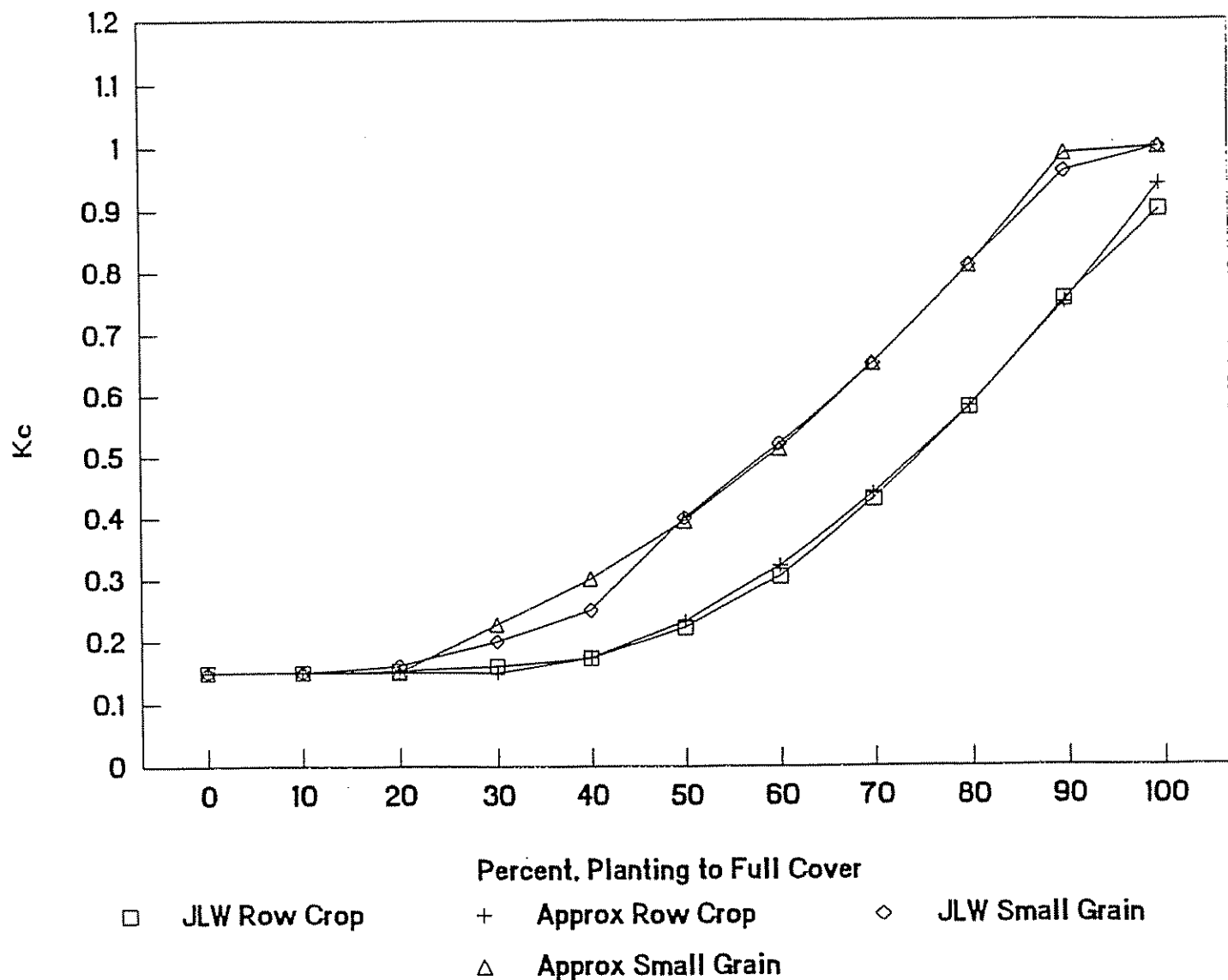
## Table 6.6, ASCE Man 70



Figure 5. Wright's daily basal crop coefficients for row crops
and small grain from planting to full cover (Wright,
Table 6.6, ASCE Manual 70).

# J L WRIGHT'S BASAL CROP COEFFICENTS
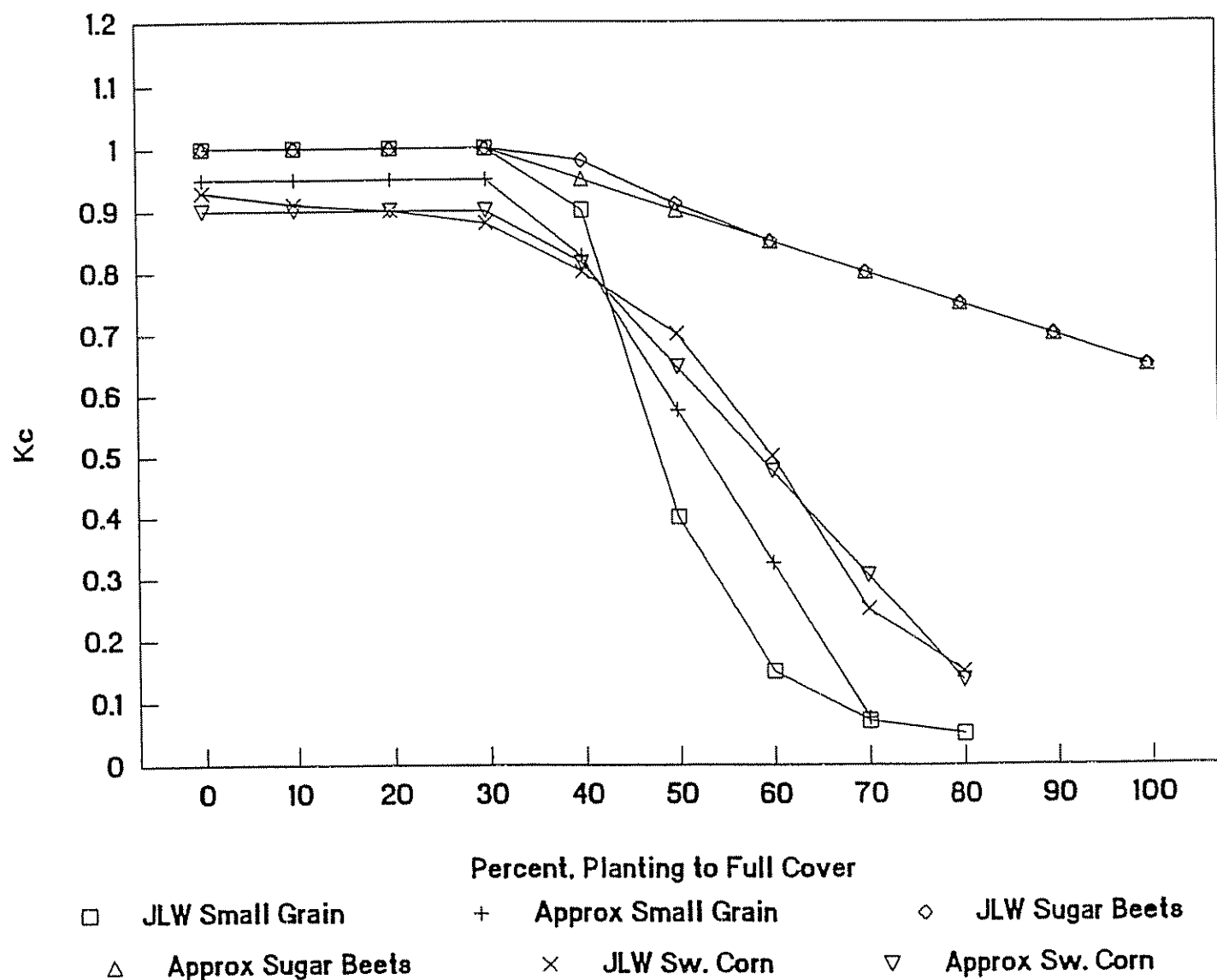
Table 6.6, ASCE Man 70



Figure 6. Wright's daily basal crop coefficients for row crops
and small grain from full cover to harvest (Wright,
Table 6.6, ASCE Manual 70).

The equation for small grain illustrated in Fig. 5 is:

$$K_{cb} = 0.15 + \frac{(P - 6)^{1.9}}{5400}, \quad for \; 6 < P < 100 \tag{3}$$

where P is the percent of the period from planting to full cover. Similar equations approximate the decrease in the coefficient as the crop matures except the value is the maximum minus the power function.

As indicated under Procedures, similar equations were fitted to the coefficients provided by JMLord, Inc. to facilitate calculating daily crop coefficient values which were multiplied by 1.2 for use with the CIMIS reference ET.

Alfalfa Coefficients. The duration of the period between alfalfa cuttings during the summer is about 30 days. A comparison of the UC, JMLord x 1.2 and Wright x 1.2 coefficients for a single period between cutting in mid-summer is shown in Figure 7. Wright's coefficients were based on seven years of daily coefficients determined using a sensitive weighing lysimeter. Clearly, the UC coefficients do not adequately represent the development of leaf area after cutting and use of UC coefficients would clearly over-estimate alfalfa ET. At this point, I decided against using UC-21427 values for quantifying ET values for the IID. Equations adjusted to fit JMLord's data point were developed for the crops involved except for citrus.

Citrus Coefficients. Because JMLord's coefficients for citrus seemed to be much higher than others being recommended, I elected to use the clean cultivated citrus coefficients developed by Pruitt as printed in Table 6.10, ASCE Manual 70.

Grape Coefficients. Although grapes is not a significant crop in the IID, it represents over 20 percent of the crops grown in the Coachella Valley Water District (CVWD). Therefore, an assessment and discussion of alternative crop coefficients for grapes needs to be made at this time. Three sets of coefficients for grapes are available for specific time periods in California: 1) Grimes and Williams (1990), 2) those suggested by C. M. Burt on 17-Sep-93, and 3) those of Pruitt's from Table 6.10, ASCE Manual 70 (Pruitt et al., 1987). Grimes and Williams coefficients are for Thompson Seedless grapes, and those of Pruitt are listed for table grapes. Burt did not specify a grape variety. The three sets of daily grape coefficients are shown in Figure 8 so that TWG suggestions can be obtained before completing ET estimates for the CVWD.

# CROP COEFFICIENTS - IID

## JML Kc x 1.2 v. UC Kc
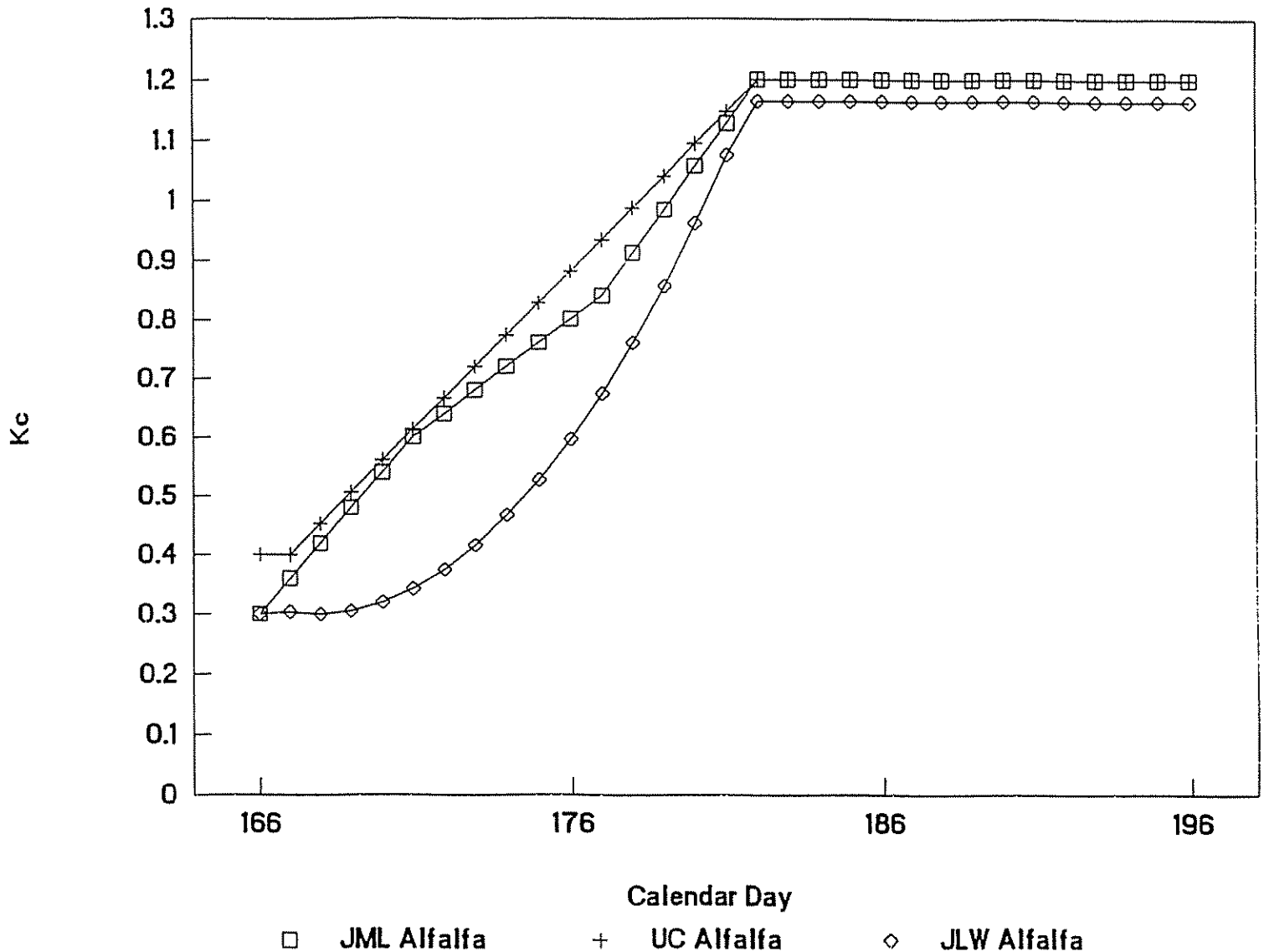


Figure 7. Comparison of UC, JMLord and Wright's daily crop
coefficients for alfalfa for a 30-day period from mid-
June to mid-July.

# GRAPE CROP COEFFICIENTS

## FOR USE WITH ETo
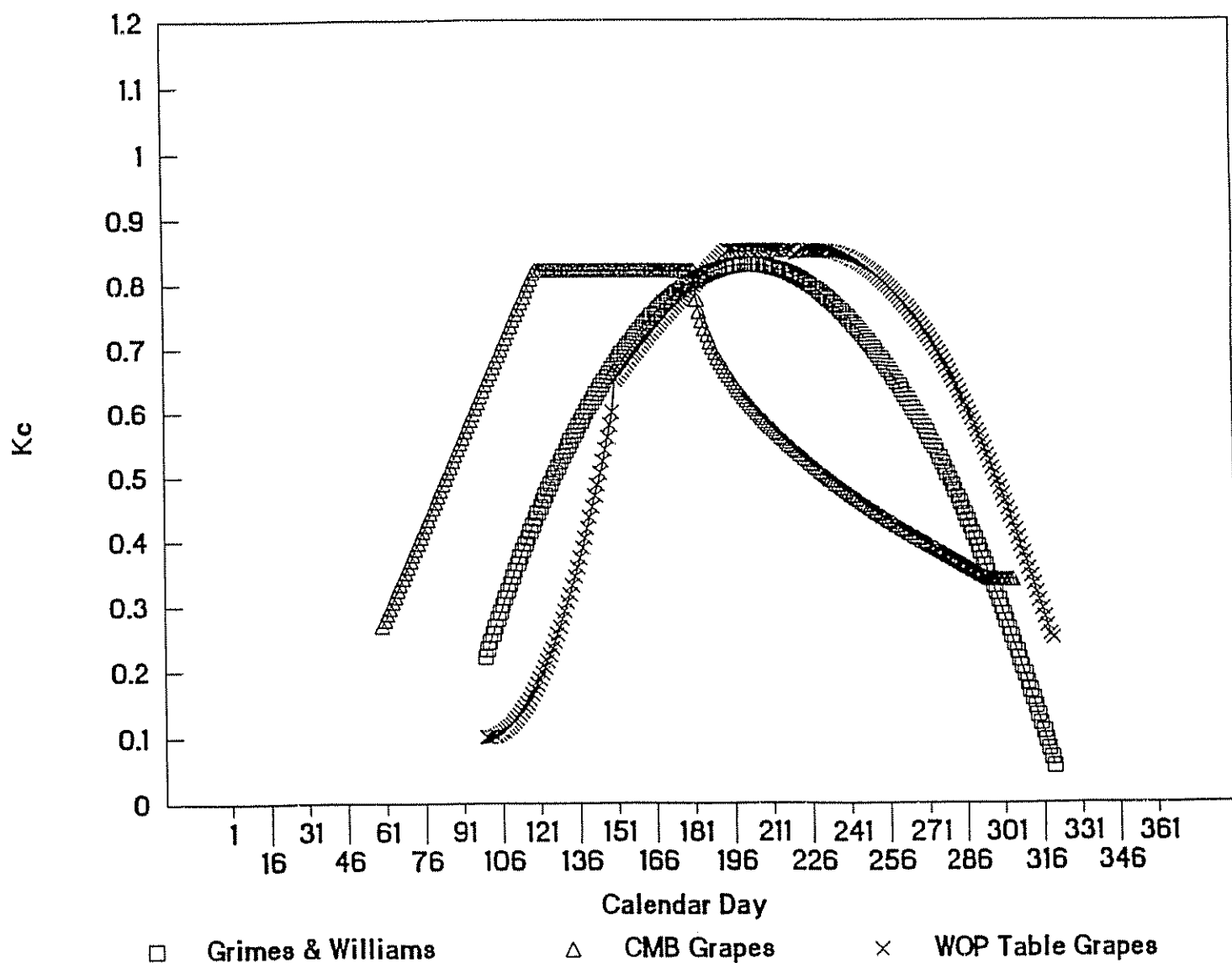


Figure 8. Comparison of three sets of crop coefficients for grapes grown in California.

## Example Application of Procedures

Alfalfa ET. Using the cutting dates suggested in UC Leaflet 21427, ET was estimated for each crop as illustrated in Figure 9 for alfalfa. Since an available soil water factor was not used, the values of the upper drained limit (field capacity), the lower limit, and management allowed depletion are not important. A graph was used for each crop because it served as a check on the procedures and crop curve being used.

Row Crop ET. An example of estimating ET for a row crop like cotton is illustrated in Fig. 10. The depth of the root zone varies with the crop coefficient.

### Example Illustration of Crop and Reference ET

An example of mean reference ET and alfalfa ET showing the effects of cuttings on ET rates for the average 1987-1992 climate is presented in Figure 11. In this case, irrigation dates were snchronized with assumed cuttings. The peaks are the cumulative increases in evaporation following rains. They are shown as occurring on single day because of the way in which they were calculated. The actual increases in evaporation would occur over several days in an exponential decreasing rate and the total for a given day would not exceed $1.2ET_o$. Pruitt's citrus coefficients were reduced to 85 percent (Figure 12).

### Adjustment of Alfalfa ET Estimates for Reported Yields

Numerous examples of alfalfa ET can be found in the literature. Specific examples of yield-ET relationships are found in more recent literature. These must be reviewed carefully because they do not always present the data in similar units or formats. A selection of data to represent a wide range in ET was used to calibrate a yield-ET relationship. At the low end and covering both dryland and irrigated alfalfa is the set of Bauder et al. (1978) who measured yield and ET over a four-year period in North Dakota. Annual ET ranged from 8 to 28.4 inches (200 to 720 mm) for the four water treatments. Dry matter yields (0% moisture) ranged from 1.2 to 5.7 tons per acre (2.6 to 12.8 t/ha).

Hill et al. (1983) summarized extensive measurements of alfalfa yield-ET data. One data set is from lysimeter measurements made in Nevada over a five-year period with ET ranging from 7 to about 50 inches and yields at 12% moisture ranging from 1 to about 10 tons/acre. Wright (1988) measured alfalfa yields in a sensitive weighing lysimeter over a 7-year period and related the lysimeter yields to the yield in the surrounding 6.4-acre field. Soil water stress was not a variable and field yields were about 5 percent less than lysimeter yields due primarily to windrow

# ESTIMATED ET and SOIL WATER- IID

CROP: ALFALFA, 1987-92
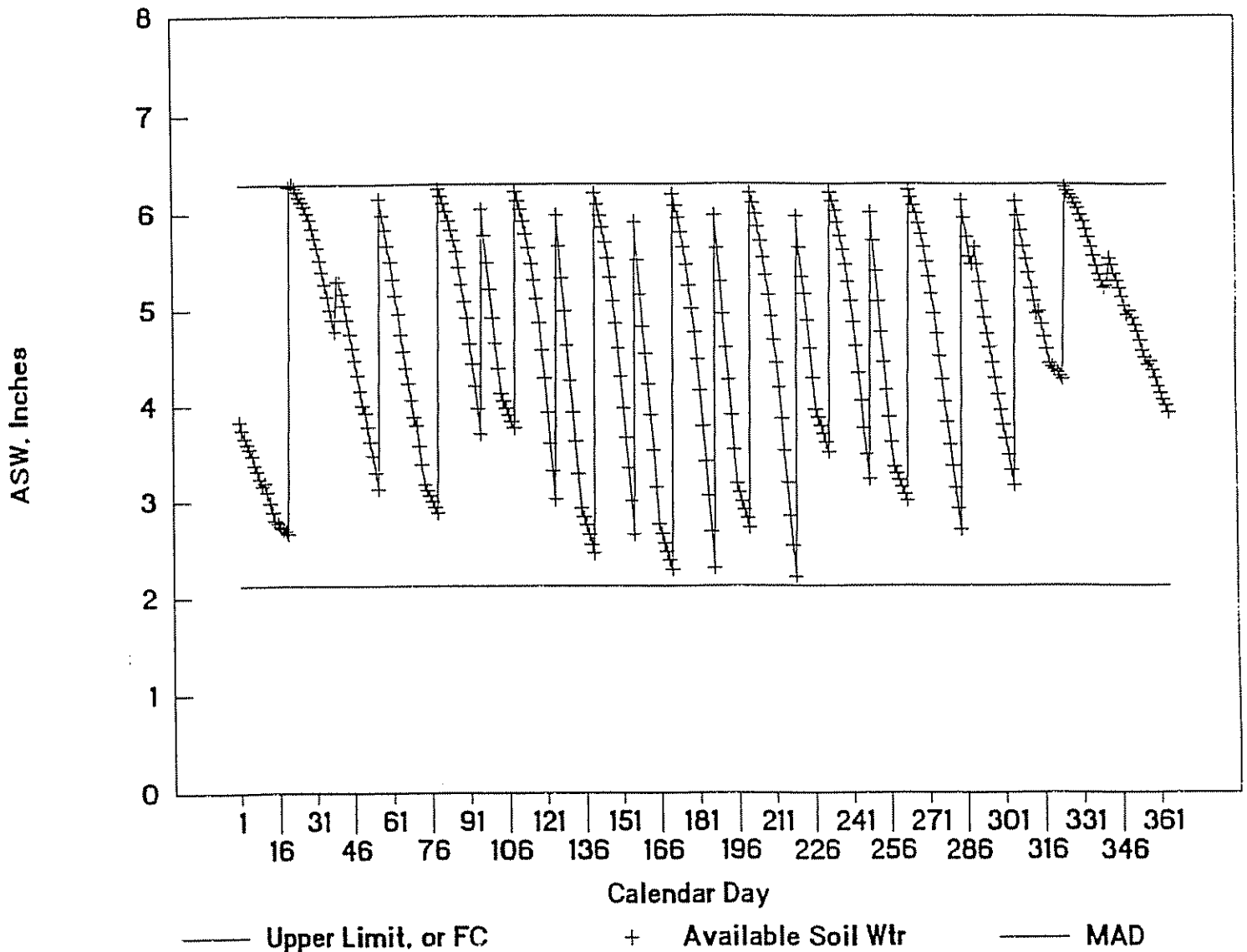


Figure 9. Example crop ET, soil water depletion, and irrigations
for a perennial crop of alfalfa with nine cuttings
scheduled according to UC Leaflet 21247 dates. A
constant root depth is used for perennial crops.

A6-18

# ESTIMATED ET and SOIL WATER - IID

CROP: COTTON, 1987-92
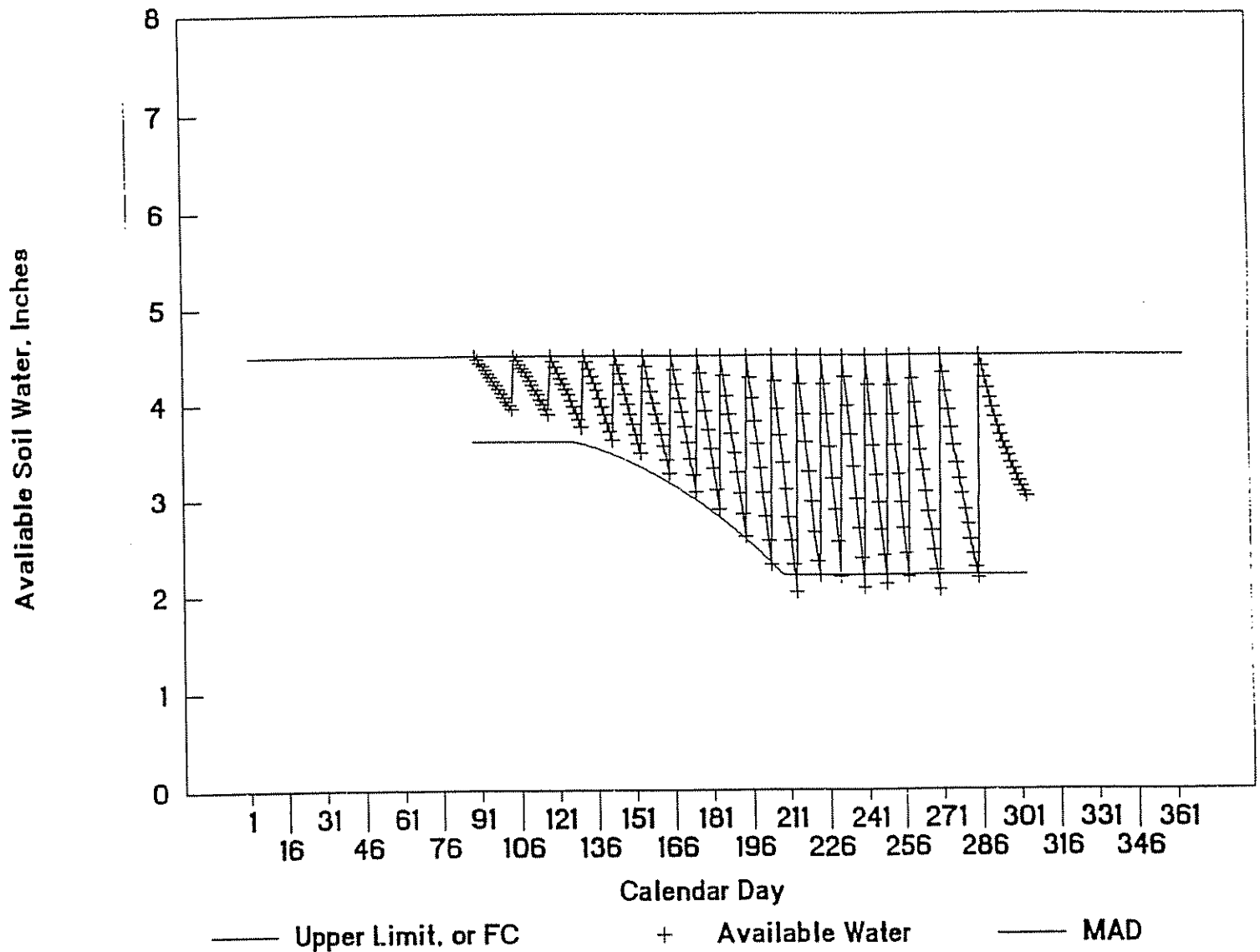


Fig. 10. Example crop ET, soil water depletion, and irrigations for an annual crop like cotton. A variable root depth related to the crop coefficient is used for annual crops.

A6-19

# CIMIS ETo and ESTIMATED ET – IID

CROP: ALFALFA, 1987-92
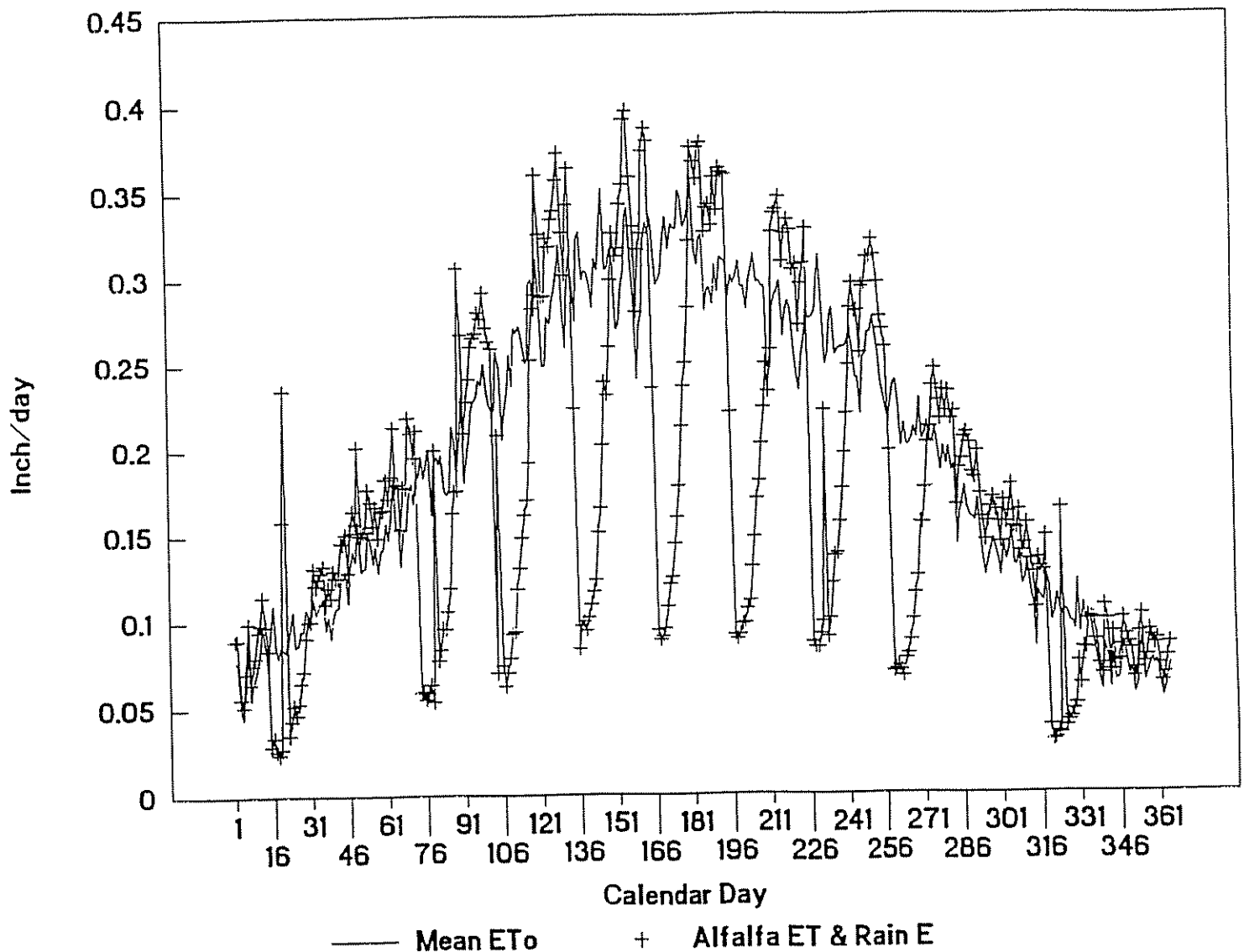


Fig. 11. Example of mean reference ET, alfalfa ET, and increases in evaporation following rains for 1987-1992 climate.

# CITRUS CROP COEFFICIENTS

## FOR USE WITH ETo
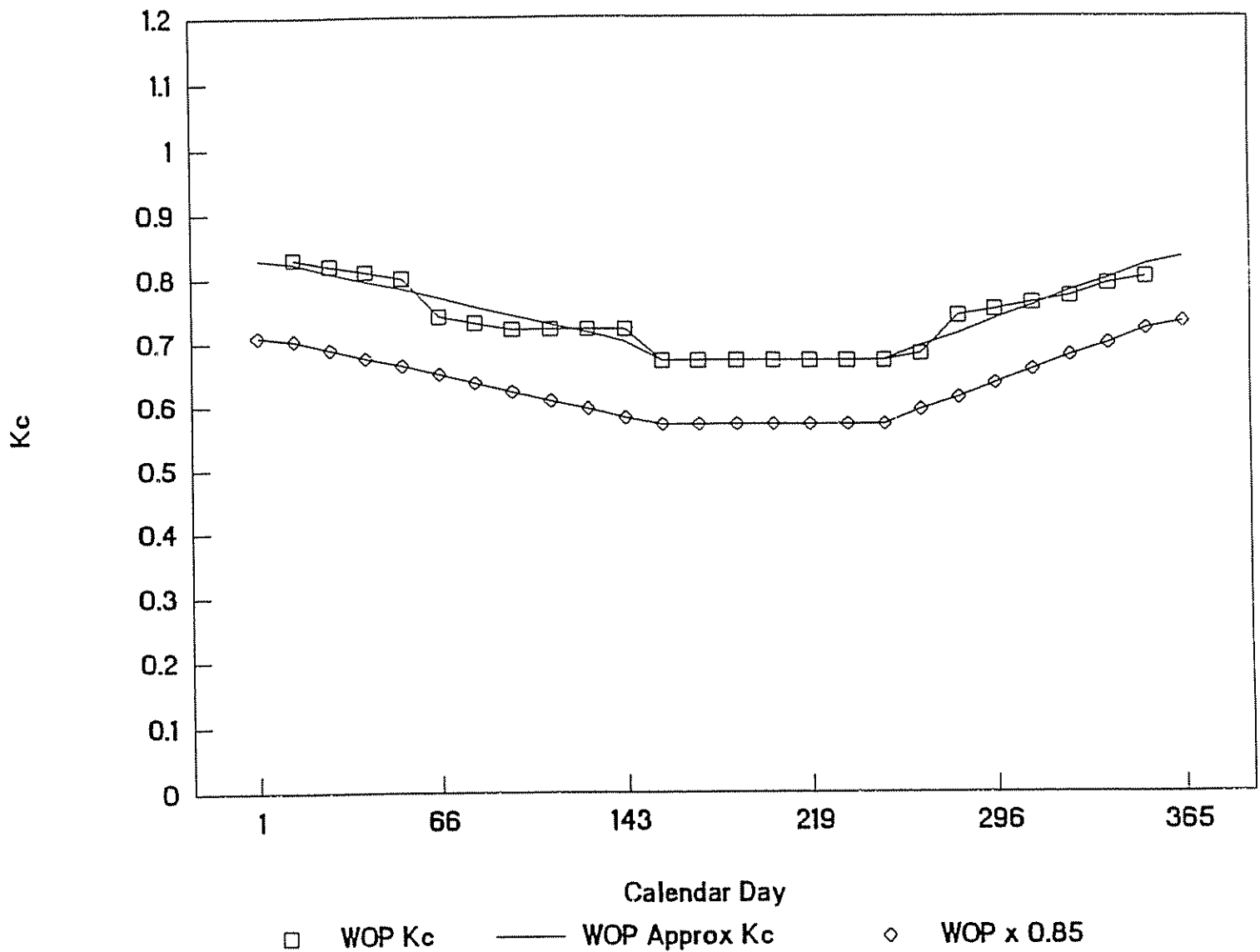


Fig. 12.  Citrus crop coefficents (From Pruitt, 1990).

effects in the field. Seasonal ET for three cuttings in mid-summer (excluding October) averaged 38.5 inches and lysimeter yields averaged 7.7 tons/acre at 12 percent moisture.

Sammis (1981) summarized alfalfa yield and ET as measured in field experiments and lysimeters. The 1979 line source values at Las Cruses, NM was from a complete year on a plot of alfalfa that was established in 1977. Yield in 1978 was not complete because of mainly mustard plants for the first cutting. Data from 1979 were selected as an example of data obtained using a sprinkler line-source method in an arid environment.

Donnavan and Meek (1983) conducted a water level yield experiment on alfalfa at the Imperial Valley Conservation Research Center from 1975 through 1977. ET was not measured, but was estimated based on the amounts of water **applied**. Yields were reported on a 10% moisture basis, but the yield-ET regression equation was for dry matter.

Because most of the data reported in the literature are in metric units and most of the values were reported as dry matter (DM, 0% moisture), a calibration of DM with ET was first carried out in metric units and later converted to alfalfa yield at both 12% moisture and 0% moisture and ET in inches. The Kimberly, Idaho lysimeter yields were also adjusted to represent field yields using the regression equation provided by Wright.

The results from the above studies are shown in Figure 13. The results from the ID, ND, NM and NV studies clearly are very close to one another. However, the Donnavan-Meek results do not agree primarily because they are based on water applied and **not measured ET.**

# ALFALFA YIELD v. ET
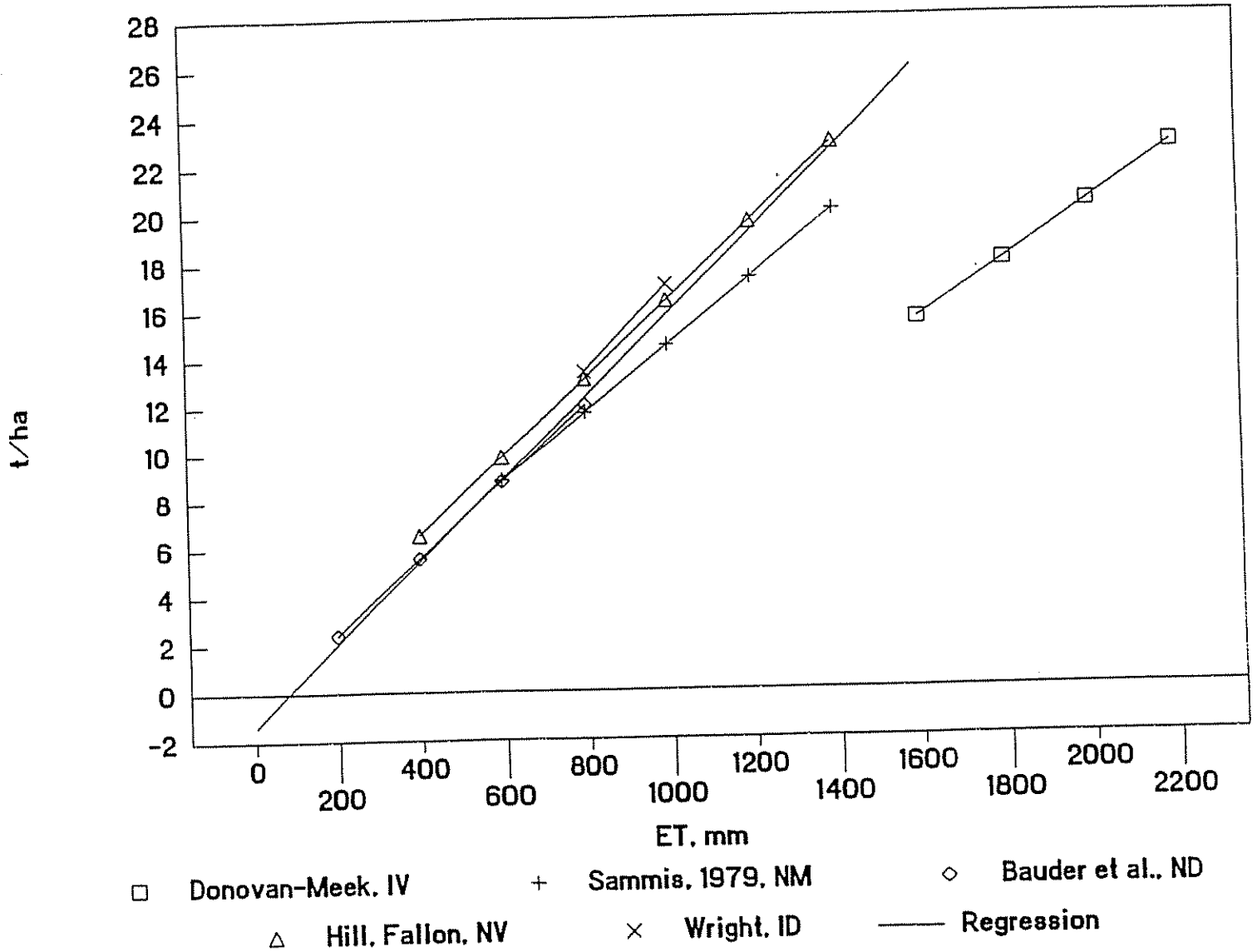


Fig. 13. Summary of alfalfa dry matter yield v. ET data and water applied data (Donnavan-Meek) expressed in metric tons per hectare.

The resulting equation that was used to estimate alfalfa yield at 12 percent moisture and ET in inches for the IID is:

$$Y = -0.70 + 0.218 ET \tag{4}$$

where Y = yield in tons/acre and ET is in annual ET in inches. When expressed as ET as a function of yield, Eq. 4 becomes:

$$ET = \frac{(Y + 0.70)}{0.218} \tag{5}$$

Assuming that cubed dehydrated has zero moisture, Eq. 4 and 5 are for "0" percent moisture.

$$Y = -0.62 + 0.194 ET \tag{4a}$$

$$ET = \frac{(Y + 0.62)}{0.194} \tag{5a}$$

The average alfalfa yields (cubed and dehydrated) for the period 1987-1992 as reported by the Imperial County Agricultural Crop and Livestock report are as follows:

|                  | Year |      |      |      |      |      |         |
|------------------|------|------|------|------|------|------|---------|
|                  | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | Average |
| Yield, tons/acre | 9.60 | 9.66 | 9.78 | 9.70 | 8.50 | 7.90 | 9.19    |

Using Eq. 5a, the average estimated ET for alfalfa is:
ET = (9.19 + 0.62)/0.194 = 50.6 inches.

This value was used in estimating average total annual ET and on-farm consumptive use coefficient, $C_{cu}$, and the farm irrigation efficiency.

## RESULTS OF ANALYSES

### Estimated ET for IID using ET x Area Method

Average Annual ET and On-Farm Irrigation Efficiency. A summary of estimated average $ET_o$, ET, rainfall, E+ (evaporation after rains), Re (effective rainfall), mean $K_t$ for the season, water delivered (From the Boyle, Styles, 1993, report), and consumptive use coeffients expressed as total ET/(water delivered) for the major crops in IID are shown on page 25. Variations in the values of ET/Wd indicate a need to refine some planting and harvest dates that were used. Effective rainfall was subtracted from total ET to estimate the fraction of irrigation water consumed.

| | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 28 | =========================================================================================================================== |
| 29 | | | | | | SUMMARY | | | | | | | | | |
| 30 | | | | | | | | | | | | Sum | | Water | 7 |
| 31 | | Period | | Foot- | | | | | | Re | Avg Kc | ET+E+ | Footnote | del | CUc |
| 32 | Crop | Start | End | note | ETo | Rain | ET | E+ | Re | | | | | | |
| 33 | | | | | | | | | | % | - - | In. | | In. | % |
| 34 | FIELD: | | | | In. | In. | In. | In. | In. | | | | | 67.7 | 71% |
| 35 | Alfalfa | 01-Jan | 31-Dec | 1 | 72.5 | 4.4 | 62.3 | 1.6 | 2.7 | 63% | 0.86 | 50.6 | 5 | 21.1 | 90% |
| 36 | Alf, Seed | 15-Mar | 01-Aug | 2 | 38.6 | 0.8 | 18.3 | 0.8 | 0.0 | 0% | 0.47 | 19.1 | 3 | 68.9 | 79% |
| 37 | Berm Grass | 01-Mar | 31-Oct | | 56.1 | 1.3 | 53.0 | 1.3 | 0.0 | 0% | 0.94 | 54.6 | | 52.2 | 72% |
| 38 | Cotton | 31-Mar | 31-Oct | | 55.7 | 1.6 | 36.5 | 1.3 | 0.2 | 16% | 0.66 | 37.8 | | 22.1 | 76% |
| 39 | Oats | 01-Jan | 30-Apr | | 18.7 | 2.1 | 16.3 | 1.3 | 0.8 | 39% | 0.87 | 17.5 | | 46.0 | 57% |
| 40 | Rye Grass | 01-Jan | 30-Apr | | 28.5 | 2.2 | 25.9 | 1.2 | 1.0 | 47% | 0.91 | 27.0 | | 58.7 | 75% |
| 41 | Sudan Gr | 01-Apr | 01-Oct | | 46.3 | 0.8 | 44.2 | 0.4 | 0.3 | 43% | 0.95 | 44.6 | | 39.6 | 75% |
| 42 | Sugar Beets1 | 30-Jun | 30-Apr | | 54.3 | 4.1 | 37.8 | 1.5 | 2.6 | 64% | 0.70 | 32.3 | 4 | 39.6 | 86% |
| 43 | Sugar Beets2 | 30-Sep | 30-Jun | | 48.2 | 3.9 | 43.8 | 1.0 | 1.8 | 47% | 0.91 | 35.7 | 4 | 30.0 | 79% |
| 44 | Wheat | 01-Jan | 31-May | | 28.2 | 2.2 | 23.3 | 1.3 | 0.9 | 42% | 0.83 | 24.6 | | | |
| 45 | | | | | | | | | | | | | | | |
| 46 | FRUIT: | | | | | | | | | | | | | 54.4 | 84% |
| 47 | Citrus | 01-Jan | 31-Dec | | 72.5 | 4.4 | 51.1 | 2.9 | 1.5 | 34% | 0.70 | 47.0 | | 79.5 | 56% |
| 48 | Peaches/Peca | 01-Apr | 15-Nov | No cov | 57.3 | 1.6 | 43.2 | 1.5 | 0.1 | 5% | 0.75 | 44.7 | | | |
| 49 | | | | | | | | | | | | | | | |
| 50 | TRUCK | | | | | | | | | | | | | 79.6 | 86% |
| 51 | Artichoke | 01-May | 10-Mar | | 62.5 | 3.9 | 70.2 | 1.3 | 3.0 | 69% | 0.97 | 71.6 | | 101.2 | 59% |
| 52 | Asparagus | 01-Jan | 31-Dec | | 72.5 | 4.4 | 57.7 | 3.2 | 1.1 | 26% | 0.80 | 61.0 | | 31.0 | 36% |
| 53 | Brocolli | 01-Oct | 01-Feb | | 13.3 | 2.2 | 9.0 | 0.8 | 1.4 | 63% | 0.68 | 12.6 | | 32.4 | 64% |
| 54 | Cant, Sprg | 31-Jan | 31-May | | 25.5 | 1.5 | 20.3 | 1.1 | 0.5 | 31% | 0.80 | 21.3 | | 19.2 | 87% |
| 55 | Cant, Fall | 31-Jul | 30-Nov | | 24.0 | 1.2 | 18.7 | 0.9 | 0.3 | 26% | 0.78 | 17.1 | | 39.8 | 48% |
| 56 | Carrots | 30-Sep | 30-Apr | | 29.6 | 3.6 | 18.0 | 2.3 | 1.3 | 37% | 0.61 | 20.3 | | 37.7 | 22% |
| 57 | Cauliflower | 01-Oct | 31-Jan | | 13.3 | 2.2 | 9.0 | 0.8 | 1.4 | 63% | 0.68 | 9.8 | | 40.0 | 48% |
| 58 | Corn, ear | 15-Jan | 15-May | | 22.0 | 2.1 | 18.8 | 1.2 | 0.8 | 40% | 0.85 | 20.0 | | 35.9 | 42% |
| 59 | Lettuce-1 | 31-Aug | 31-Dec | | 17.8 | 1.7 | 16.1 | 0.4 | 1.3 | 76% | 0.90 | 16.5 | | 35.9 | 44% |
| 60 | Lettuce-2 | 31-Oct | 31-Mar | | 17.2 | 3.0 | 17.1 | 0.9 | 2.0 | 69% | 0.99 | 18.0 | | 24.2 | 66% |
| 61 | Melons,HDF | 01-Aug | 31-Dec | | 31.8 | 2.1 | 15.8 | 1.2 | 0.9 | 42% | 0.50 | 16.9 | | 40.8 | 35% |
| 62 | Melons,Wtr | 01-Jan | 30-Apr | | 18.7 | 2.1 | 13.6 | 1.5 | 0.6 | 29% | 0.73 | 15.0 | | 52.8 | 59% |
| 63 | Onions | 01-Jan | 31-May | | 37.3 | 2.3 | 31.5 | 1.1 | 1.2 | 53% | 0.84 | 32.6 | | 51.4 | 61% |
| 64 | Onion Seed | 01-Jan | 31-May | | 37.3 | 2.3 | 31.5 | 1.1 | 1.2 | 53% | 0.84 | 32.6 | | 43.7 | 59% |
| 65 | Tomatoes,S | 31-Jan | 31-May | | 34.8 | 1.7 | 25.8 | 0.9 | 0.8 | 45% | 0.74 | 26.7 | | | |

67   1.   Same for row and flat alfalfa.
68   2.   Assume production of hay up to 15-March.
69   3.   For only the seed-producing period.
70   4.   Sugar beet harvest begins before the last date of the period. Total ET+E+ was reduced by the
71       average of the last two months (assumes that harvest takes place over two months).
72   5.   (ET + E+) reduced based on regression equation of alfalfa Y-ET using data from locations with
73       many years of Y-ET data (New Mexico, Nevada, Idaho, and North Dakota), and average IID yields for 1987-1992.
74       ET = (Y + 0.62)/0.194, ET in inches and yield in tons/acre at 0 moisture.
75   6.   Several periods, such as for broccoli, cauliflower, etc. need to be verified.
76   7.   The irrigation water consumptive use coefficient, CUc, is CUc = 100(ETc - Re)/Water delivered.

Crop acreages summarized from the Boyle (Styles, 1993) report, percentage distribution of these acreages, and the estimated confidence interval are presented in the spreadsheet on page A6-27. The Boyle ET values are from the Boyle CVWD report. The estimated average ET from planting to harvest (excluding preplant-irrigations and evaporation losses) is 1,586,200 ac-ft with an estimated minimum of 1,517,100 and a maximum of 1,655,300 ac-ft.

The average on-farm irrigation consumptive use coefficient was 65 percent. The confidence range of 61 to 70 percent. Estimated effective rainfall, though small, was subtracted from total ET in these calculations.

<u>Variation in Annual On-Farm Consumptive Use Coefficient for 1987-1992</u>. A summary of estimated on-farm consumptive use coeficent and $CU_c$ plus LR by years considering ET from planting to harvest is presented in Figure 14. Individual years were modified to reflect the differences in mean $ET_0$ for individual years and crop acreages in individual years.

## Evaluation of Water Delivery v. CIMIS Annual Reference ET

The results clearly show decreasing on-farm consumption of irrigation water from 1987 through 1991. During the same period, the amount of water delivered relative mean annual reference ET times the cropped area increased. These results show that water deliveries were not reduced as evaporative demand decreased. The trends changed somewhat in 1992.

The above trends are supported by data reported by IID showing farm drainage discharge into the Salton Sea. At this time, I did not have data for 1992. The increase in runoff to the Salton Sea from 1987 through 1991 during years of decreasing evaporative demand supports the above statement that there appears to be a lack of response to changing evaporative demand as measured by the CIMIS. Other factors may have been involved such as the lining of canals during this period which would reduce seepage losses. Adjusting for such changes may not yet have been taken into account.

## Summary of Weather-Based ET Estimates

On-farm ET represents the major consumption of irrigation water delivered to the district. The annual value of $(1 - CU_c)$ should approximate the fraction of irrigation water delivered that drained into the Salton Sea. A comparison of $(1 - CU_c)$ with the ratio of drainage to the Salton Sea relative to the total flow at Drop 1 indicates that these preliminary ET estimates for the IID appear reasonable.

| 79 | ========================================================================================================================= |

| | | Crop Distribution | | | | | Confidence interval | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 80 | | | | | | | | | | | | |
| 81 | | 550,178 | 100.0% | Sum | Ac x | Distr- | Crop | Normalized | | | | |
| 82 | Crop | Average | | ET+E+-Re | ET-Re | ibution | ET | CV | CV^2 | | Boyle (CVWD) | |
| 83 | ------------- | | | | | | | | | | | |
| 84 | FIELD CROPS: | Acres | Pct | Ac-ft/ac | Ac-ft | % | % | | | | In. | Ft |
| 85 | Alfalfa, row | 29,872 | 5.4% | 4.0 | 119,151 | 7.5% | 10% | 0.0038 | 1.41E-05 | | 70.1 | 5.8 |
| 86 | Alfalfa, flat | 156,710 | 28.5% | 4.0 | 625,063 | 39.4% | 10% | 0.0197 | 3.88E-04 | | 70.1 | 5.8 |
| 87 | Alfalfa Seed | 6,619 | 1.2% | 1.6 | 10,535 | 0.7% | 10% | 0.0003 | 1.10E-07 | | | |
| 88 | Bermuda Grass | 6,608 | 1.2% | 4.6 | 30,064 | 1.9% | 10% | 0.0009 | 8.98E-07 | | | |
| 89 | Bermuda Seed | 9,845 | 1.8% | 4.6 | 44,793 | 2.8% | 10% | 0.0014 | 1.99E-06 | | | |
| 90 | Cotton | 12,960 | 2.4% | 3.1 | 40,576 | 2.6% | 7% | 0.0009 | 8.02E-07 | | | |
| 91 | Oats | 2,443 | 0.4% | 1.4 | 3,400 | 0.2% | 10% | 0.0001 | 1.15E-08 | | | |
| 92 | Rye Grass | 8,143 | 1.5% | 2.2 | 17,660 | 1.1% | 10% | 0.0006 | 3.10E-07 | | | |
| 93 | Sudan Grass | 44,594 | 8.1% | 3.7 | 164,510 | 10.4% | 10% | 0.0052 | 2.69E-05 | | | |
| 94 | Sugar Beets | 39,095 | 7.1% | 2.7 | 103,601 | 6.5% | 10% | 0.0033 | 1.07E-05 | | | |
| 95 | Wheat | 64,491 | 11.7% | 2.0 | 127,192 | 8.0% | 10% | 0.0040 | 1.61E-05 | | | |
| 96 | Other | 2,021 | 0.4% | 1.4 | 2,812 | 0.2% | 10% | 0.0001 | 7.86E-09 | | | |
| 97 | Subtotal | 383,400 | 69.7% | | | 81.3% | | | | | | |
| 98 | FRUIT CROPS: | | | | | | | | | | | |
| 99 | Citrus | 2,221 | 0.4% | 3.8 | 8,425 | 0.5% | 10% | 0.0003 | 7.05E-08 | | 45.0 | 3.8 |
| 100 | Peaches/Pecans | 382 | 0.1% | 3.7 | 1,419 | 0.1% | 10% | 0.0000 | 2.00E-09 | | | |
| 101 | Other | 6 | 0.0% | 0.0 | 0 | 0.0% | 10% | 0.0000 | 0.00E+00 | | | |
| 102 | Subtotal | 2,609 | 0.5% | | | 0.6% | | | | | | |
| 103 | TRUCK CROPS: | | | | | | | | | | | |
| 104 | Artichoke | 415 | 0.1% | 5.7 | 2,368 | 0.1% | 15% | 0.0001 | 1.25E-08 | | | |
| 105 | Asparagus | 5,658 | 1.0% | 5.0 | 28,215 | 1.8% | 15% | 0.0013 | 1.78E-06 | | | |
| 106 | Broccoli | 9,731 | 1.8% | 0.9 | 9,109 | 0.6% | 15% | 0.0004 | 1.85E-07 | | 14.3 | 1.2 |
| 107 | Cantaloupes, S | 18,974 | 3.4% | 1.7 | 32,968 | 2.1% | 15% | 0.0016 | 2.43E-06 | | | |
| 108 | Cantaloupes, F | 7,400 | 1.3% | 1.4 | 10,357 | 0.7% | 15% | 0.0005 | 2.40E-07 | | | |
| 109 | Carrots | 13,234 | 2.4% | 1.6 | 20,918 | 1.3% | 15% | 0.0010 | 9.78E-07 | | 21.0 | 1.8 |
| 110 | Cauliflower | 6,037 | 1.1% | 0.7 | 4,267 | 0.3% | 15% | 0.0002 | 4.07E-08 | | | |
| 111 | Corn, Ear | 2,499 | 0.5% | 1.6 | 4,002 | 0.3% | 15% | 0.0002 | 3.58E-08 | | | |
| 112 | Lettuce | 29,070 | 5.3% | 1.3 | 37,785 | 2.4% | 15% | 0.0018 | 3.19E-06 | | 15.5 | 1.3 |
| 113 | Melons, HD, F | 1,326 | 0.2% | 1.3 | 1,772 | 0.1% | 15% | 0.0001 | 7.02E-09 | | | |
| 114 | Melons, Wtr | 3,462 | 0.6% | 1.2 | 4,163 | 0.3% | 15% | 0.0002 | 3.87E-08 | | | |
| 115 | Onions | 10,061 | 1.8% | 2.6 | 26,314 | 1.7% | 15% | 0.0012 | 1.55E-06 | | | |
| 116 | Onion Seed | 2,358 | 0.4% | 2.6 | 6,168 | 0.4% | 15% | 0.0003 | 8.50E-08 | | | |
| 117 | Tomatoes, S | 6,970 | 1.3% | 2.2 | 15,093 | 1.0% | 15% | 0.0007 | 5.09E-07 | | | |
| 118 | Veg, mixed | 1,320 | 0.2% | 2.2 | 2,858 | 0.2% | 15% | 0.0001 | 1.83E-08 | | | |
| 119 | Misc. | 7,516 | 1.4% | 2.2 | 16,276 | 1.0% | 15% | 0.0008 | 5.92E-07 | | | |
| 120 | Subtotal | 125,617 | 22.8% | | | 14.0% | | | | | | |
| 121 | MISC: | | | | | | | | | | | |
| 122 | Duck Pd/Fish F | 8,768 | 1.6% | 5.7 | 49,980 | 3.2% | 10% | 0.0016 | 2.48E-06 | | 87.7 | 7.3 |
| 123 | Miscellaneous | 2,214 | 0.4% | 5.7 | 12,622 | 0.8% | 10% | 0.0004 | 1.58E-07 | | | |
| 124 | Leaching | 3,102 | 0.6% | 0.6 | 1,768 | 0.1% | 10% | 0.0001 | 3.11E-09 | | | |
| 125 | Subtotal | 14,085 | 2.6% | | | 4.1% | | | | | Range of estimates | |

| 126 | ------------------------------------------------------------------------------------------Sum CV^2   CV^0.5   Min   Max |

| | | | | | | | | | Sum CV^2 | CV^0.5 | Min | Max |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 127 | Total | | | | 1,586,203 | | Std dev = 34,552 | | 4.74E-04 | 0.0217 | 1,517,099 | 1,655,307 |
| 128 | Average water delivered to agric. users | | | | 2,426,349 | | Boyle (1993) 5% | 0.0250 | 6.25E-04 | 0.025 | 2,305,032 | 2,547,666 |
| 129 | Total variance, ET and water delivered | | | | | | | | 0.001099 | 0.0331 | | |
| 130 | On-farm consumptive use coefficient | | | | | 65.4% (Excluding LR) | | Std dev= | 3.3% | 61.0% | 69.7% | |

| 131 | --------------------------------------------------------------------------------------------------------------------------- |

# CU, LR & WTR DEL/ETo x CROP AREA – IID

## CU BY ET x CROP AREA -- 1987--1992



Legend:
□  CUc, Var A & ETo        +  (CUc+LR), Var A&ETo        ◇  Water Del/EToxArea
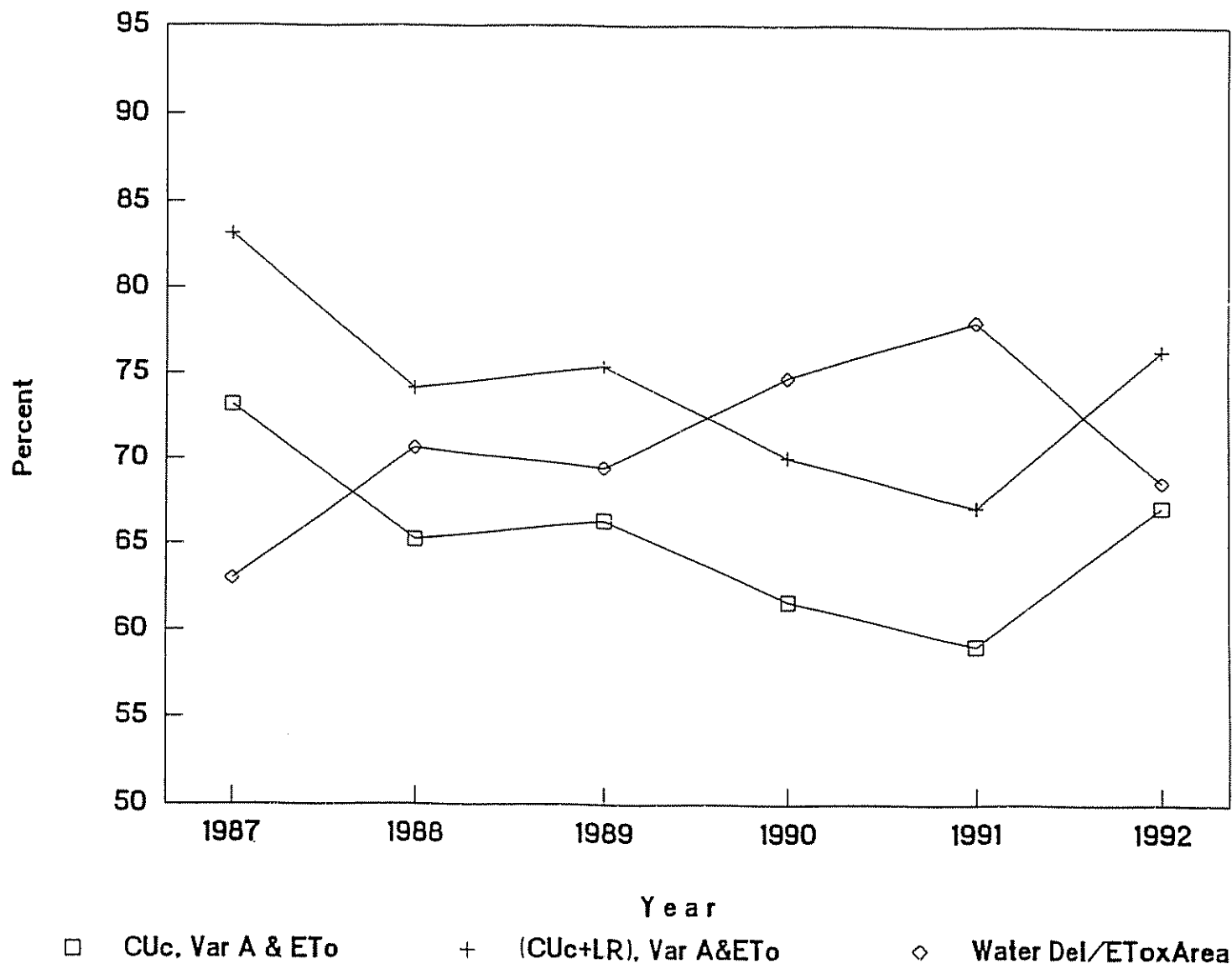
Fig. 14.   Estimated on-farm consumptive use coefficients and
           percentage of water delivered relative to reference
           ET/cropped area by year.

# ESTIMATED IRRIG CU v. RETURN FLOW - IID

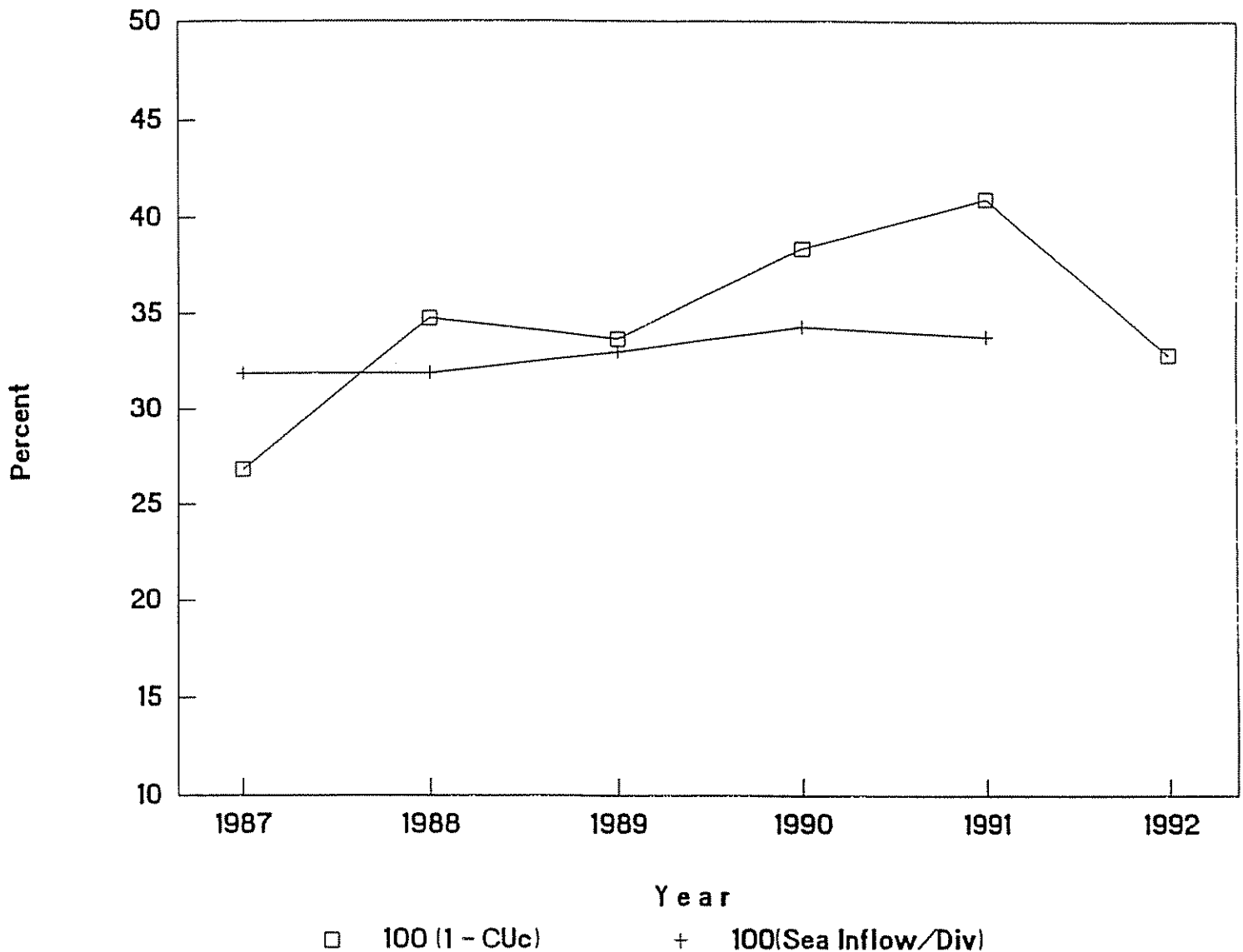## CU BY (ET-Re) x CROP AREA -- 1987-1992



Fig. 15.  Variation in $(1 - CU_c)$ and ratio of water drained the
Salton Sea to total flow at Drop 1.

## SUMMARY AND CONCLUSIONS

ET can be estimated with reasonable accuracy using existing crop coefficients and reference ET measured by CIMIS. Data on the range of planting, crop development, and harvest dates and leaf-area development rates will be needed in Phase II to enable refining ET estimates. The estimates of mean annual ET relative to water deliveries in the IID from 1987 through show that IID irrigation water orders and deliveries did not respond to decreasing evaporative demand as measured by the CIMIS. Increasing farm drainage to the Salton Sea during the same period shows the same general trend.

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# APPENDIX A6-A

## GENERAL PROCEDURES USED AND ASSUMPTIONS FOR ESTIMATING ET

Specific spreadsheet files that were used can be made available if needed. However, they are not fully automated and require some manual adjustments in changing crops. Generic equations AND coefficients for calculating crop coefficients from planting to full cover and days after full cover will be summarized in a separate report in Phase II. Input data and assumptions or conditions assumed in estimating evapotranspiration are summarized below:

INPUT DATA:

**Climate:**
Mean daily CIMIS ETo values were derived from Stations 41, 68 and 87 for the period 1987-1992.

**Rainfall:**
Mean distribution of rainfall events from CIMIS stations 41, 68 and 87.

**Cropping Dates:**
Cropping dates were derived mainly from UC Leaflet 21427 and IID "Schedule of Major Crops".

**Crop Coefficients:**
Mainly daily cropping coefficients were based on generalized curves based on JMLord coefficients multiplied by 1.2 for use with CIMIS reference ET. Several curves were from W.O. Pruitt (ASCE Manual 70, page 127. The shape of the crop curves were based on daily lysimeter-based data from J.L. Wright (ASCE Manual 70).

**Soil:**
Drained upper limit (FC) = 36 percent by volume; Lower Limit = 21 percent by volume. Source: ASCE Manual 70, p. 21.

**Effective Rain:**
Total rainfall minus the increase in evaporation due to rain, E+, was estimated using the equation given on p. 118, ASCE Manual 70. No runoff was assumed for the small events.

**ASSUMPTIONS:**
1. Soil water was assumed adequate and did not limit ET.
2. No increase in evaporation, E+, was added at this time due to wetting following irrigations because irrigation frequency was not known. Frequency is dependent on soil type, depth to the water table and its effects, etc. Data on irrigation frequency collected in Phase II will enable estimating this component of ET.

# APPENDIX 7


## EVAPOTRANSPIRATION AND FARM
## CONSUMPTIVE USE ESTIMATES FOR CVWD

# APPENDIX 7

## EVAPOTRANSPIRATION AND FARM CONSUMPTIVE USE ESTIMATES FOR CVWD

by
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21 December 1993

### INTRODUCTION

The Technical Work Group (TWG) is using several approaches to estimating farm irrigation efficiency. One approach is to estimate evapotranspiration (ET) for major crop groups and then multiply the ET by crop acreages to arrive at total ET. Estimating ET for the various crops grown in the Coachella Valley Water District (CVWD) required summarizing six years of climatic data and selecting and adapting crop coefficient values for convenient use on a daily basis using a spreadsheet approach. For future routine computations, a software program in BASIC or FORTRAN should be considered as it will simplify recalculations as crop coefficients and/or planting and harvest dates are updated.

The major input variable used in this analysis was reference ET ($ET_0$) provided by CIMIS station 50 at Thermal, California. Disk file copies (UPDATE.DBF and UPDATE1.DBF) of CIMIS data used in preparing the summary data in the Boyle (Styles, 1993) report were used in this study as was done for evaluating reference ET estimates.

The procedures used in this analysis were essentially the same as used for making ET estimates in the Imperial Irrigation District (IID) except for four crops (alfalfa, citrus, dates and grapes). Yield-based estimates of alfalfa ET were not used for CVWD. No estimates were made for citrus ET in IID. Pruitt's 1990 citrus coefficients were reduced by 15 percent for CVWD and two methods of estimating ET for dates were used and averaged. No ET estimates were made for dates in the IID.

### PROCEDURES

#### Alternative Mean Climate Data Sets

Six years of daily $ET_0$ values were available from CIMIS station 50 (Thermal) for the period 1987-1992. The station was moved between 1989 and 1990 to a site that is more representative of irrigated crops. Five years of data were available from CIMIS Station 55 (Palm Desert), but the $ET_0$ values for that site were about 10 percent less than those at Station 50 during the period 1990-1992. A check of the main variables affecting $ET_0$ at the two sites indicated that the wind speeds at Station 55 were about

2/3 of those at Station 50. This indicates that CIMIS site 55 may not be representative of agricultural crops. Therefore, reference ET values from Station 55 were not used in establishing the set of mean daily reference ET values.

The overlap in data between stations 50 and 55 did provide a means for adjusting the CIMIS 50 reference ET values from 1987 through 1989 to be comparable with 1990-1992 values. The 1987-1989 values were increased 5.2 percent to compensate for the net effect of the move. A summary of the annual total reference ET values for Stations 50 and 55 before and after adjustment are shown in Fig. 1 along with mean reference ET values for IID.

The adjusted six-year values for Station 50 show a general decrease from 1987 to 1992, which is similar though not as large as that in IID. The six-year mean annual reference ET values for the two sites were essentially the same, 75.1 inches for IID and 74.2 inches for CVWD.

As noted for IID ET estimates, daily estimates for individual years were not made because a matrix of 2192 rows would have been required. With repetitive applications of crop coefficients, a spreadsheet approach would have been very cumbersome and the resulting spreadsheet would have been very large.

The alternative approach of establishing a set of mean daily $ET_o$ for 365 days based on the data available from CIMIS Station 50 was selected. Even with this reduced matrix, a computer software that enabled using expanded memory was required when estimating ET for individual crops and converting and saving individual crop ET values. Four spreadsheet files were used to enable estimating and saving ET values for all of the crops.

### Crop Coefficients

Two primary sources of crop coefficients ($K_c$) were evaluated before selecting coefficients for various crops: 1) University of California Leaflet 21427, and 2) a set of coefficients provided by JMLord, Inc. The ASCE Manual 70 and several other references provided alternative values for some crops. Leaflet 21427 (UC, undated) provided starting point information about planting and harvest dates for many crops. For dates, crop ET estimates using coefficients from JMLord, Inc. appeared to be too low when compared with ET estimates using $ET/R_t$ ratios derived from a four-year study by Pillsbury (1941) conducted in the Coachella Valley during the years 1932 and 1936-38. JMLord's coefficients may have been based on Pillsbury's data which were estimates of **transpiration** and not ET.

Pillsbury's estimates of transpiration were made by taking soil moisture samples below the surface soil mulch of about 5 inches

# REFERENCE ET – CIMIS 50
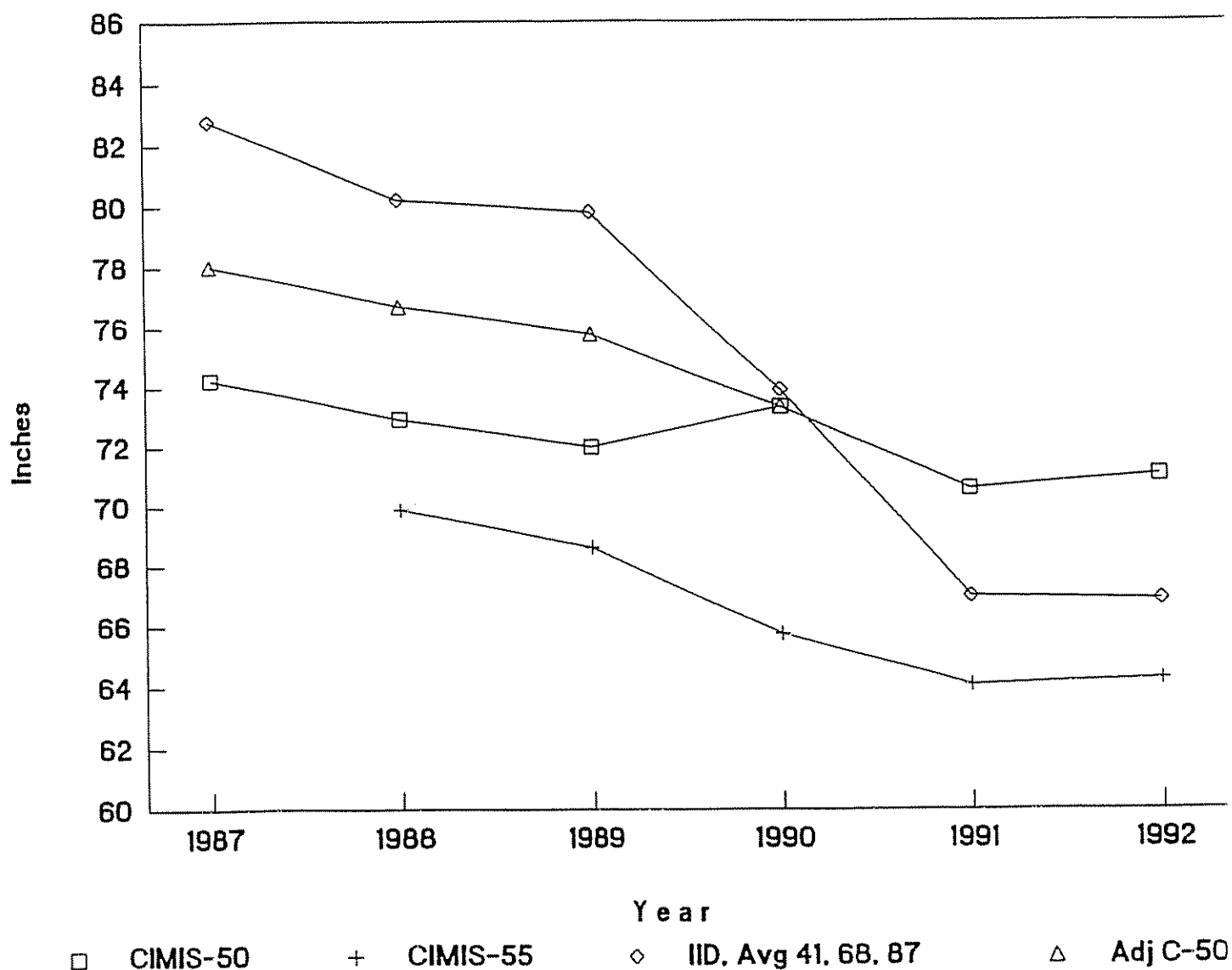## THERMAL (50), & PALM DESERT (55), CA



Figure 1. Mean annual reference ET from CIMIS Stations 50 and 55, adjusted reference ET values for 1987-1989 for Station 50, and mean reference ET for the IID which is the mean of CIMIS Stations 41 (Mulberry), 68 (Seeley) and 87 (Meloland).

during periods between irrigations. During the early 1960s, I estimated that the 5-inch soil layer lost as much moisture by evaporation as the next soil layer sampled to arrive at estimates of ET for use in the article by Jensen and Haise (1963). Solar radiation was not measured but was estimated using cloud cover data for the years involved. The resulting mean monthly $ET/R_s$ ratios were included in the 1963 publication. These ratios were used with mean 1987-92 solar radiation data to provide alternative estimates of ET for dates.

As reported in my ET report for IID, I was **not** able to use daily crop coefficients derived from UC Leaflet 21427 in quantifying ET values for most crops because the values clearly do not represent real crop development characteristics. **The UC coefficients appear to be intended for management purposes such as irrigation scheduling and possibly for establishing peak ET values for determining system capacity requirements. They do not appear adequate for estimating the quantity of ET.**

The data set provided by JMLord, Inc. has five values for the growth period from planting to full cover (0, 25, 50, 75, and 100 %), and four values for growth periods after full cover (growth intervals 1, 2, 3 and 4). Applying these coefficient on a daily basis would have required interpolation between two data points for seven periods for each crop. This procedure would have been very cumbersome using a spreadsheet approach. Therefore, generic equations for daily values were calibrated for the two periods, 1-100 percent of full cover and days after full cover. This approach required only two equations for each crop instead of seven. The generic equations were based on shape of crop coefficient curves that were developed from daily lysimeter data for row crops and close-planted crops by Wright as summarized in ASCE Manual 70 (Jensen et al., 1990). Since, the JMLord crop coefficients were developed for use with an alfalfa reference crop, they were multiplied by 1.2 for use with CIMIS $ET_o$.

### Rainfall Values for the Mean Climatic Data Set

Rainfall data from the Thermal, California provided by the CVWD were summarized and grouped into discrete rainfall events for each month of the year. Then, based on the average number of rain storms of different sizes, a set of monthly rain storms was selected to provide approximately the same average total annual rainfall for the 1987-1992 period. With these average rainfall events, an estimate of effective rainfall for each crop was obtained.

## Effective Rainfall

Since most all of the individual rainfall events in the data set were small, no runoff was assumed and the increase in evaporation following a rain event was based on the following equations (ASCE Manual 70, page 118):

$$E+ = 0.35(1.5 + t_d)(K_1 - K_a K_{cb}) ET_o \tag{1}$$

where E+ = the increase in evaporation following wetting of the soil and foliage, $t_d$ is the number of days for the soil surface to visually appear dry (7 days was used for a fine texture soil), $K_1$ is the maximum value of $K_c$ after a rain or irrigation (1.2 was used), $K_{cb}$ is the basal crop coefficient, and $K_a$ is a dimensionless coefficient that is dependent on available soil water ($K_a = 1.0$, soil water not limiting, was used for this analysis). The maximum value of E+ could not exceed the rainfall received.

### Major Crop Groupings

A large number of crops are grown in the CVWD, but many represent a very small percentage of the irrigated crop land. The most recent crop acreage data provided by JMLord, Inc. grouped most of the truck crops under **miscellaneous vegetables**. Therefore, CVWD reports of individual crops acreages to the USBR and crop acreages from the Boyle (Styles, 1993) report were used to approximate individual crop acreages. A mean six-year summary of major crop acreages was used to estimate the total ET for the average 1987-1992 period.

### Cropping Period for ET Estimates

Estimates of ET were made from planting to harvest. Soil water was assumed to be at the drained upper limit, or field capacity, at planting for a fine texture soil (ASCE Manual 70, page 21). Since no information was available on irrigation frequency or rooting depth, available soil water was not assumed to affect ET.

### Evaporation Losses after Preplant-Irrigations

Since crop ET estimates were desired, no estimates of evaporation losses during and after preplant-irrigations were included in my estimates. Assuming that preplant-irrigations were made prior to planting or for germinating seeds, evaporation estimates can be made in Phase II. **Estimates of evaporation after both pre-plant irrigations and irrigations during the growing season would need to be added when comparing water balance estimates with crop ET x area estimates.**

### Adjusting ET Estimates for Alfalfa

Because the soils in the CVWD are more permeable than in the IID, soil water was not assumed to limit alfalfa growth. Therefore, no adjustment of estimated alfalfa ET based on yields was made.

### Evaporation Estimates for Duck Ponds, Fish Farms & Leaching

Average evaporation estimates for ponds and reservoirs in my report "Evaluating Evaporation Estimates for IID" were used for duck ponds, fish farms, farm reservoirs, and for areas being leached. It was assumed that areas being leached remained flooded for at least a month. Therefore, 1/10 of annual pond evaporation was used for estimates of evaporation during leaching. Also, based on the percentage of the cropped land in IID that was reported being leached by flooding (less than 1 percent), I assumed that 1 percent of the fallow/leach area in the CVWD was being leached in any one year.

### Total ET, CU Coefficient and Farm Irrigation Efficiency

Total ET was obtained by multiplying crop ET by the estimated crop acreage. The farm irrigation consumptive use coefficient, $CU_c$, was estimated by dividing the estimated ET of irrigation water by the sum of the estimated Colorado River water delivered to farms and an estimate of ground water pumped which was from Colorado River water. An estimate of farm irrigation efficiency was also obtained by including an average leaching requirement of 0.12.

## INTERMEDIATE RESULTS OF PROCEDURES

### Mean Reference ET Data Set

The six-year mean daily reference ET, $ET_o$, from CIMIS Station 50 is presented in Fig. 2. The small dip in reference ET values during May-June is similar to the dip reported during the 1960s USGS Salton Sea study (Hely et al., 1966).

### Mean Annual Rainfall Distribution Data Set

An analysis of rainfall events for CIMIS station 50 is summarized in Table 1. For the average 1986-1992 year, the number of rainfall events and amounts are summarized in Table 2. In the IID, 80 percent of the rainfall events produced 0.0 to 0.25 inch of precipitation. CVWD rainfall events were distributed over a wider range than in the IID. Based on the frequency of rainfall events, only 28 percent fall in the range of 0 - 0.25 inch compared to 80 percent in IID, 33 percent in 0.26-0.50 inch v. 16 percent in IID, and 20 percent in 0.51-0.75 inch v. 3 percent in IID. The events that produced more than 0.75-inch was 18 percent

# AVERAGE REFERENCE ET – CVWD
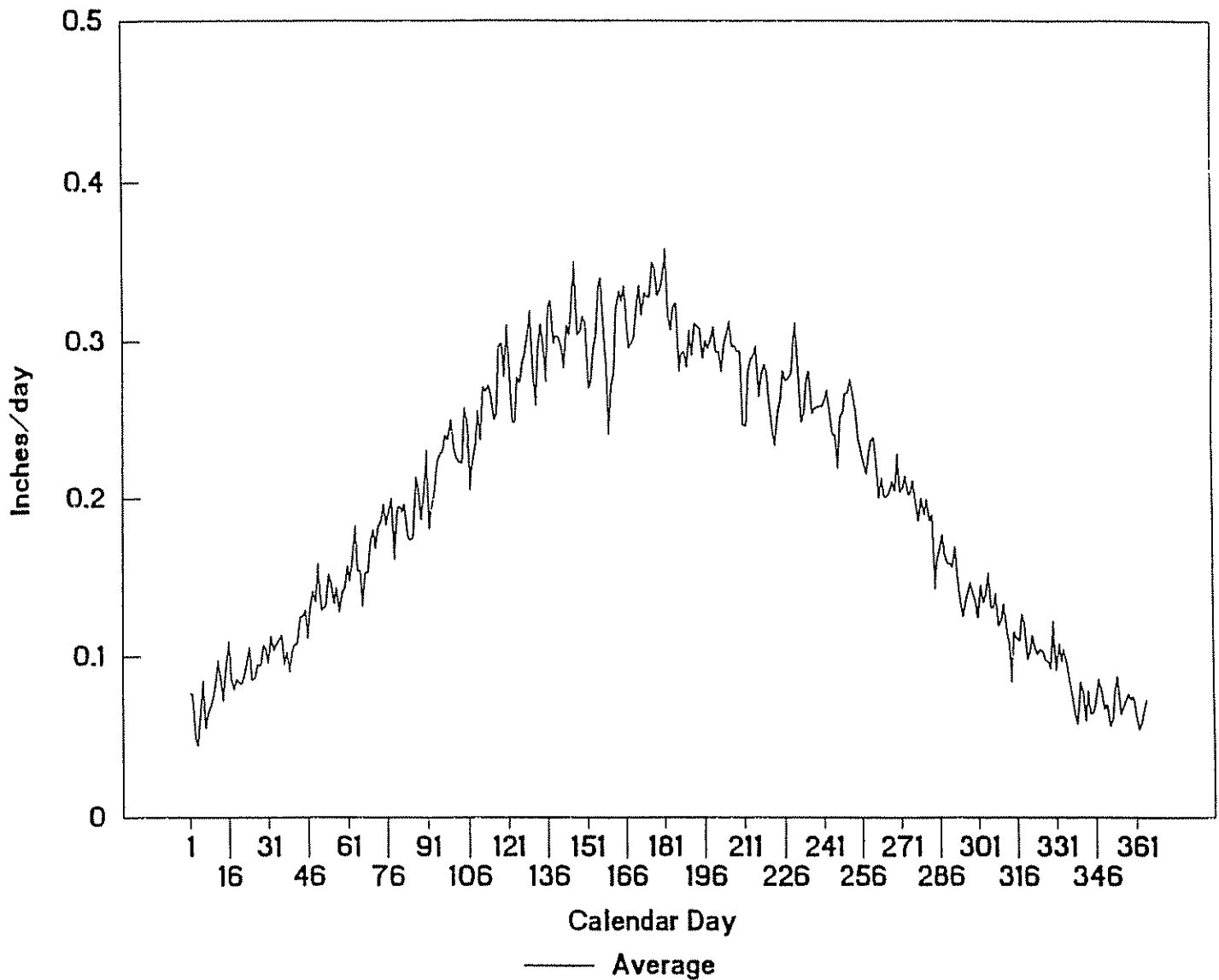
## CIMIS STATION 50 -- 1987-92



Figure 2. Mean daily ET from CIMIS Stations 50 (Thermal) for
1987-1992.

Table 1. Average number of annual rainfall events in each of seven ranges of amounts from 1986 through 1992.

| Month | Range, inches 0- 0.20 | 0.21- 0.40 | 0.41- 0.60 | 0.61- 0.80 | 0.81- 1.00 | 1.01- 1.20 | 1.21- 1.40 |
|---|---|---|---|---|---|---|---|
| Jan | 1.29 | 0.29 | 0.43 | 0 | 0 | 0 | 0 |
| Feb | 1.00 | 0 | 0.14 | 0 | 0.43 | 0.14 | 0 |
| Mar | 1.43 | 0.57 | 0.43 | 0.14 | 0 | 0 | 0 |
| Apr | 0.57 | 0.14 | 0 | 0 | 0 | 0 | 0 |
| May | 0.43 | 0 | 0 | 0 | 0 | 0 | 0 |
| Jun | 0.14 | 0 | 0 | 0 | 0 | 0 | 0 |
| Jul | 0.86 | 0 | 0 | 0 | 0 | 0 | 0 |
| Aug | 0.57 | 0.14 | 0 | 0 | 0 | 0 | 0 |
| Sep | 1.00 | 0.14 | 0 | 0 | 0 | 0 | 0 |
| Oct | 0.71 | 0.71 | 0 | 0.14 | 0 | 0 | 0 |
| Nov | 0.86 | 0.14 | 0.14 | 0 | 0 | 0 | 0 |
| Dec | 1.86 | 0.43 | 0.29 | 0 | 0 | 0 | 0 |

Avg. rain 1.07   0.77   0.71   0.20   0.39   0.16   0
Total average annual rainfall                          3.3

Table 2. Number of rainfall events and amounts used for the average 1987-1992 year in each of seven ranges of amounts.

| Month | Range, inches 0- 0.20 | 0.21- 0.40 | 0.41- 0.60 | 0.61- 0.80 | 0.81- 1.00 | 1.01- 1.20 | 1.21- 1.40 | Total |
|---|---|---|---|---|---|---|---|---|
| Jan | 1 | 1 | | | | | | 0.4 |
| Feb | 1 | | | 1 | | | | 0.8 |
| Mar | 1 | 1 | | | | | | 0.4 |
| Apr | 1 | | | | | | | 0.1 |
| May | 1 | | | | | | | 0.1 |
| Jun | 1 | | | | | | | 0.1 |
| Jul | 1 | | | | | | | 0.1 |
| Aug | 1 | | | | | | | 0.1 |
| Sep | 1 | | | | | | | 0.1 |
| Oct | 1 | 1 | | | | | | 0.4 |
| Nov | 1 | | | | | | | 0.1 |
| Dec | 2 | 1 | | | | | | 0.5 |
| Events | 12 | 4 | 0 | 1 | 0 | 0 | 0 | 18 |
| Rain | 1.2 | 1.2 | 0 | 0.7 | 0 | 0 | 0 | 3.2 |

v. only 1 percent in the IID. The average rainfall for the period was 3.3 inches. Additional details can be found in my report entitled "Evaluating Effective Rainfall in CVWD" dated 01-Oct-1993.

## Crops and Cropping Periods

The major crops and the estimated periods of growth used for making ET estimates are summarized in Table 3. Also shown are the estimates of ET and the ET values used in the Boyle report (Styles, 1993). The acres of each crop are summarized in a later spreadsheet table. Some of the planting and harvest dates were obtained from UC Leaflet 21427 and others from the Boyle report.

## Crop Coefficients

University of California Crop Coefficients. In my IID ET report, daily UC crop coefficient values were first calculated for individual days for the growth periods. As I indicated in my IID report, the changes in the coefficients for crop growth are represented by the straight lines. When compared with other coefficients that change in relation to leaf area development (See Figure 3), the UC crop coefficients are not realistic for estimating the **quantity** of water consumed in ET

JMLord, Inc. Coefficients. Crop coefficients after plant emergence increase with plant growth or leaf area. The rate of leaf area development typically increases as a function of leaf area as illustrated in Figures 4 for the period before full cover and in the ET decrease with maturity as illustrated in Figure 5 for days after full cover. The values in Figures 4 and 5 were based on daily crop coefficient values determined using lysimeter measurements of ET. The curves in the figures are of an exponential or power function type for use with alfalfa as the reference crop. For example, the average equation for row crops (sugar beets, potatoes, corn and beans) illustrated in Figure 4 is:

$$K_{cb} = 0.15 \frac{(P - 30)^{1.8}}{2650} \ , for \ 30 < P < 100 \tag{2}$$

The equation for small grain illustrated in Fig. 5 is:

$$K_{cb} = 0.15 + \frac{(P - 6)^{1.9}}{5400}, \quad for \ 6 < P < 100 \tag{3}$$

where P is the percent of the period from planting to full cover. Similar equations approximate the decrease in the coefficient as the crop matures except the value is the maximum minus the power function.

As indicated under Procedures, similar equations were fitted to the coefficients provided by JMLord, Inc. to facilitate calculating daily crop coefficient values which were multiplied by 1.2 for use with the CIMIS reference ET.

Table 3. Summary of major crops, growth periods dates, days between planting and full cover, and days between full cover and harvest for CVWD as used in estimating ET. For Phase II, refinement is needed in dates which will require assessing the range planting dates, leaf area development rates and the range of harvest dates.

| Row | 24-Feb-94 | | | | SUMMARY OF ET ESTIMATES FOR CVWD - 1987-1992 | | | | | | | \SUMET-CV | | CVWD | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 28 | ===================================================================================================================== | | | | | | | | | | | | | | |
| 29 | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P |
| 30 | | | | | | SUMMARY | | | | | | | | Boyle (1993) | |
| 31 | | Period | | Foot- | | | | | | | | Sum | | Table 6-4 | (3) |
| 32 | Crop Start | | End | note | ETo | Rain | ET | E+ | Re | Re | Avg Kc | ET+E+ | Footnote | Inches | |
| 33 | | | | | | | | | | | | | | | |
| 34 | FIELD: | | | | In. | In. | In. | In. | In. | % | - - | In. | | | |
| 35 | Alfalfa | 01-Jan | 31-Dec | 1 | 74.3 | 3.1 | 63.9 | 1.6 | 2.7 | 88% | 0.86 | 65.5 | 1 | 70.1 | |
| 36 | Cotton | 31-Mar | 31-Oct | | 57.4 | 0.9 | 38.4 | 0.8 | 0.1 | 11% | 0.67 | 39.2 | | | |
| 37 | Sudan Gr | 01-Apr | 01-Oct | | 39.5 | 0.3 | 35.6 | 0.2 | 0.1 | 33% | 0.90 | 35.8 | | | |
| 38 | Wheat & SmG | 01-Jan | 31-May | | 28.7 | 1.8 | 25.9 | 0.9 | 0.9 | 51% | 0.90 | 26.8 | | | |
| 39 | | | | | | | | | | | | | | | |
| 40 | FRUIT: | | | | | | | | | | | | | | |
| 41 | Citrus | 01-Jan | 31-Dec | | 74.3 | 3.1 | 47.0 | 2.2 | 0.9 | 29% | 0.63 | 49.2 | | 45.0 | |
| 42 | Dates | 01-Jan | 31-Dec | | 74.3 | 3.1 | 64.3 | 2.6 | 0.5 | 16% | 0.87 | 66.9 | 2 | 73.1 | |
| 43 | Grapes | 14-Feb | 20-Sep | | 57.5 | 0.9 | 38.9 | 0.9 | 0.0 | 0% | 0.68 | 39.8 | | 39.9 | |
| 44 | Other T frt | 01-Apr | 15-Nov | No cov | 58.7 | 1.0 | 45.3 | 1.0 | 0.0 | 0% | 0.77 | 46.3 | | | |
| 45 | | | | | | | | | | | | | | | |
| 46 | TRUCK | | | | | | | | | | | | | | |
| 47 | Beans | 01-Oct | 01-Mar | | 16.9 | 2.2 | 12.0 | 0.7 | 1.5 | 68% | 0.71 | 12.7 | | | |
| 48 | Brocolli | 15-Sep | 15-Feb | | 18.5 | 2.3 | 12.3 | 0.9 | 1.4 | 61% | 0.66 | 13.2 | | 14.3 | |
| 49 | Carrots | 30-Sep | 30-Apr | | 30.1 | 2.7 | 20.0 | 1.6 | 1.1 | 41% | 0.66 | 21.6 | | 21.0 | |
| 50 | Corn, sw | 15-Jan | 15-May | | 22.9 | 1.8 | 20.6 | 1.0 | 0.8 | 44% | 0.90 | 21.6 | | | |
| 51 | Lettuce-1 | 31-Aug | 02-Jan | | 18.1 | 1.1 | 16.6 | 0.4 | 0.7 | 64% | 0.92 | 17.0 | | 15.5 | |
| 52 | Onions | 01-Jan | 31-May | | 29.0 | 1.8 | 29.4 | 0.8 | 1.0 | 56% | 1.01 | 30.2 | | | |
| 53 | Peppers | 01-Nov | 31-May | | 34.1 | 2.4 | 30.7 | 1.3 | 1.1 | 46% | 0.90 | 32.0 | | | |
| 54 | Potatoes | 01-Nov | 16-May | | 29.1 | 2.4 | 21.3 | 1.3 | 1.1 | 46% | 0.73 | 22.6 | | | |
| 55 | Squash | 01-Feb | 31-May | | 26.2 | 1.4 | 19.7 | 0.8 | 0.6 | 43% | 0.75 | 20.5 | | | |
| 56 | Watermelon | 01-Jan | 31-May | | 28.7 | 1.8 | 23.0 | 1.1 | 0.7 | 39% | 0.80 | 24.1 | | | |
| 57 | Misc veget | 01-Nov | 30-Jun | | 34.1 | 2.4 | 30.7 | 1.3 | 1.1 | 46% | 0.90 | 32.0 | | | |
| 58 | Nurseries | 01-Nov | 31-Dec | | 13.2 | 1.4 | 12.7 | 0.7 | 0.7 | 50% | 0.96 | 13.4 | | | |
| 59 | Ponds | 01-Jan | 31-Dec | | 74.3 | 3.1 | 72.8 | 0 | 3.1 | 100% | 0.98 | 72.8 | 4 | 87.7 | |
| 60 | | | | | | | | | | | | | | | |

61 1. Other cutting dates are: 8/15; 9/15; 11/15; 01/15; 03/15; 04/15; and 05/15.
62 2. Average of estimated ET with JHLord coefficients and estimated ET with Jensen and Haise (1963) ET/Rs coefficients.
63    Jensen, M.E., and H.R. Haise. 1963. Estimating evapotranspiration from solar radiation. J. Irrig. and Drain. Div.,
64    Am. Soc. Civ. Engr. 89(IR4):15-41.
65 3. Styles, S. 1993. On Farm Irrigation Efficiency - Special Technical Report, Coachella Valley Water District, April.
66 4. Jensen, M.E. 1993. Report on Evaporation Estimates for IID. 18-Oct, 10 pp + Appendices A & B.
67
68
69
70

# CROP COEFFICIENTS – IID

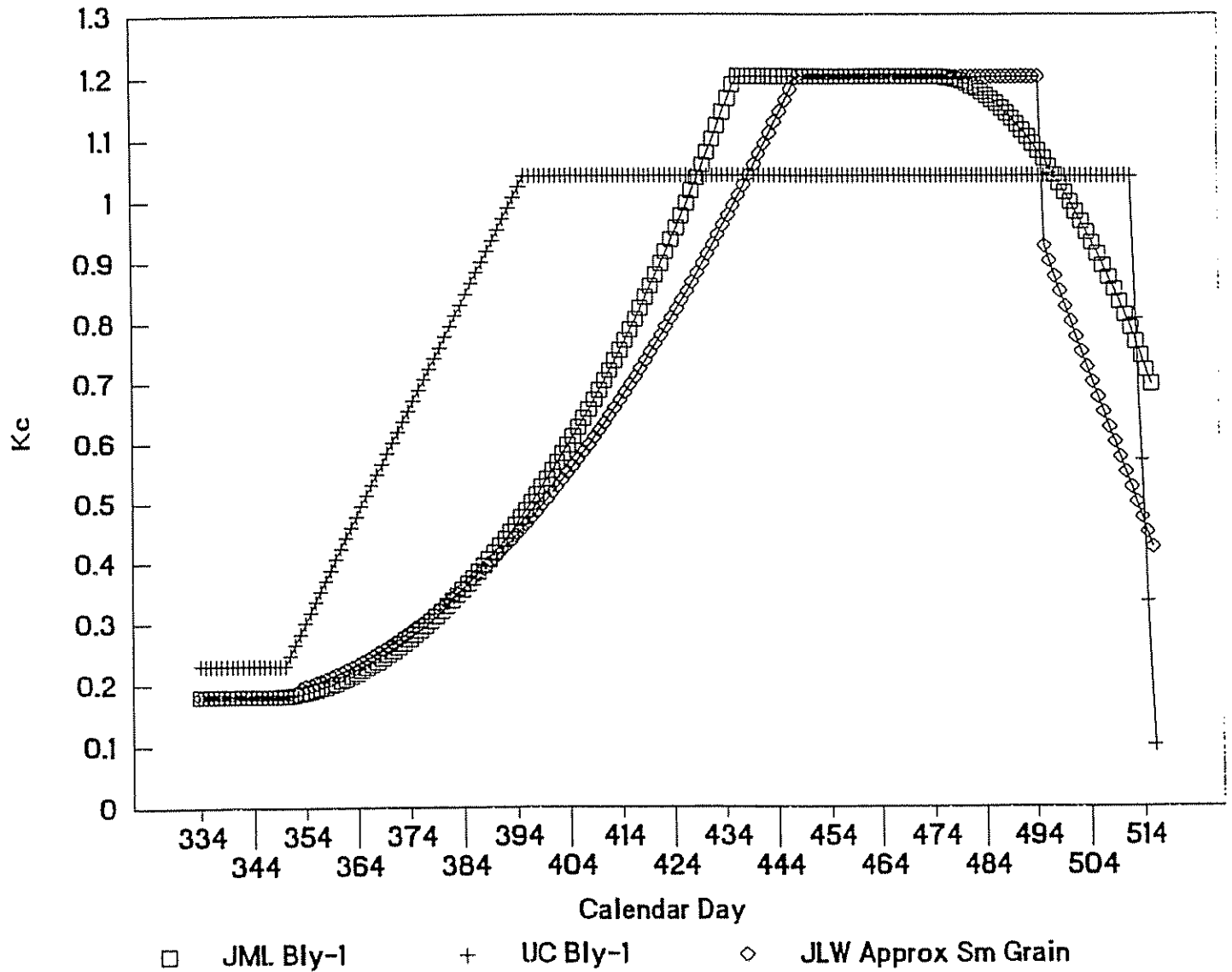## JML Kc x 1.2 v. UC Kc



Figure 3. Comparison of UC, JMLord, and Wright's daily crop coefficients for barley.

# J L WRIGHT'S BASAL CROP COEFFICENTS
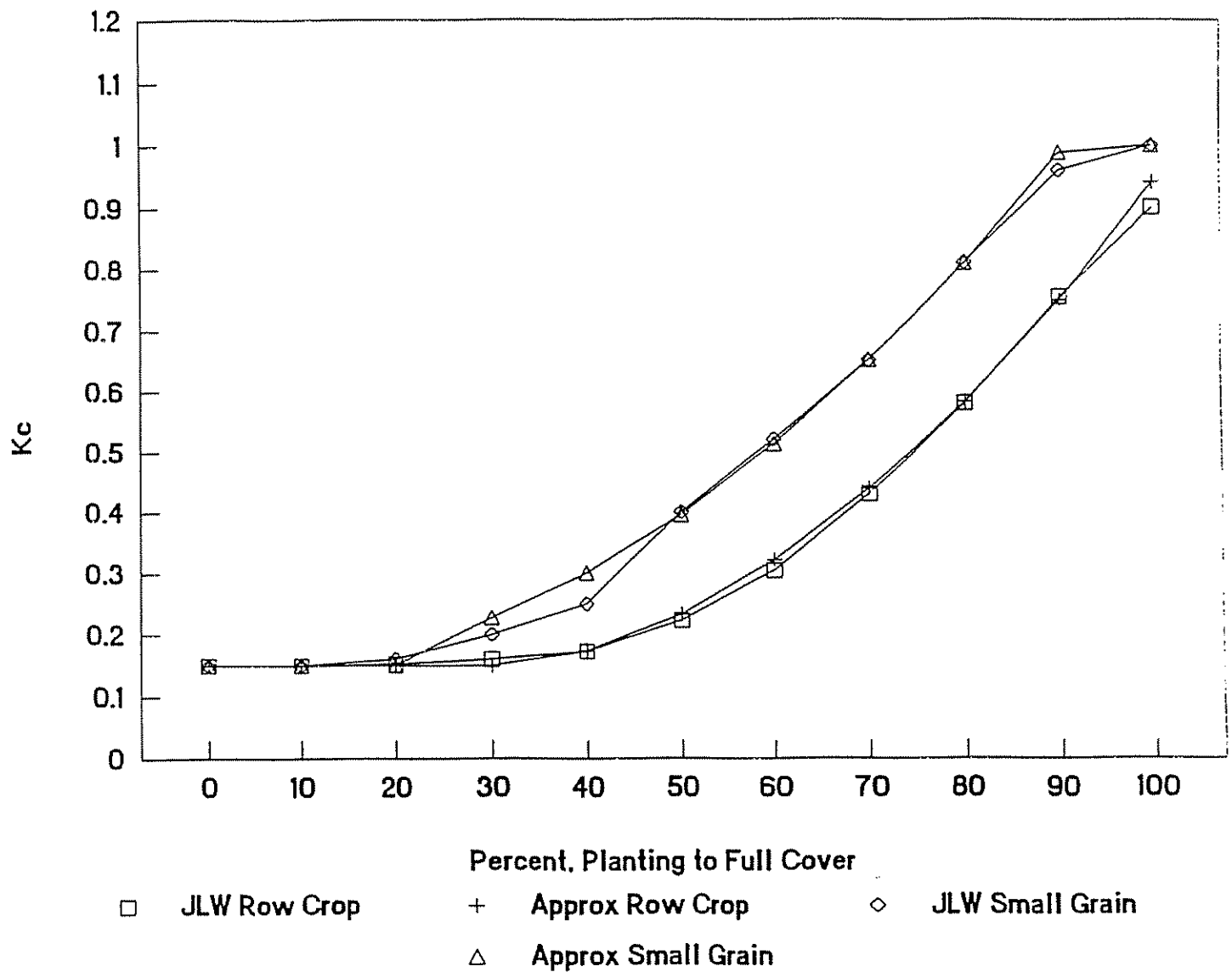## Table 6.6, ASCE Man 70



Figure 4. Wright's daily basal crop coefficients for row crops and small grain from planting to full cover (Wright, Table 6.6, ASCE Manual 70).

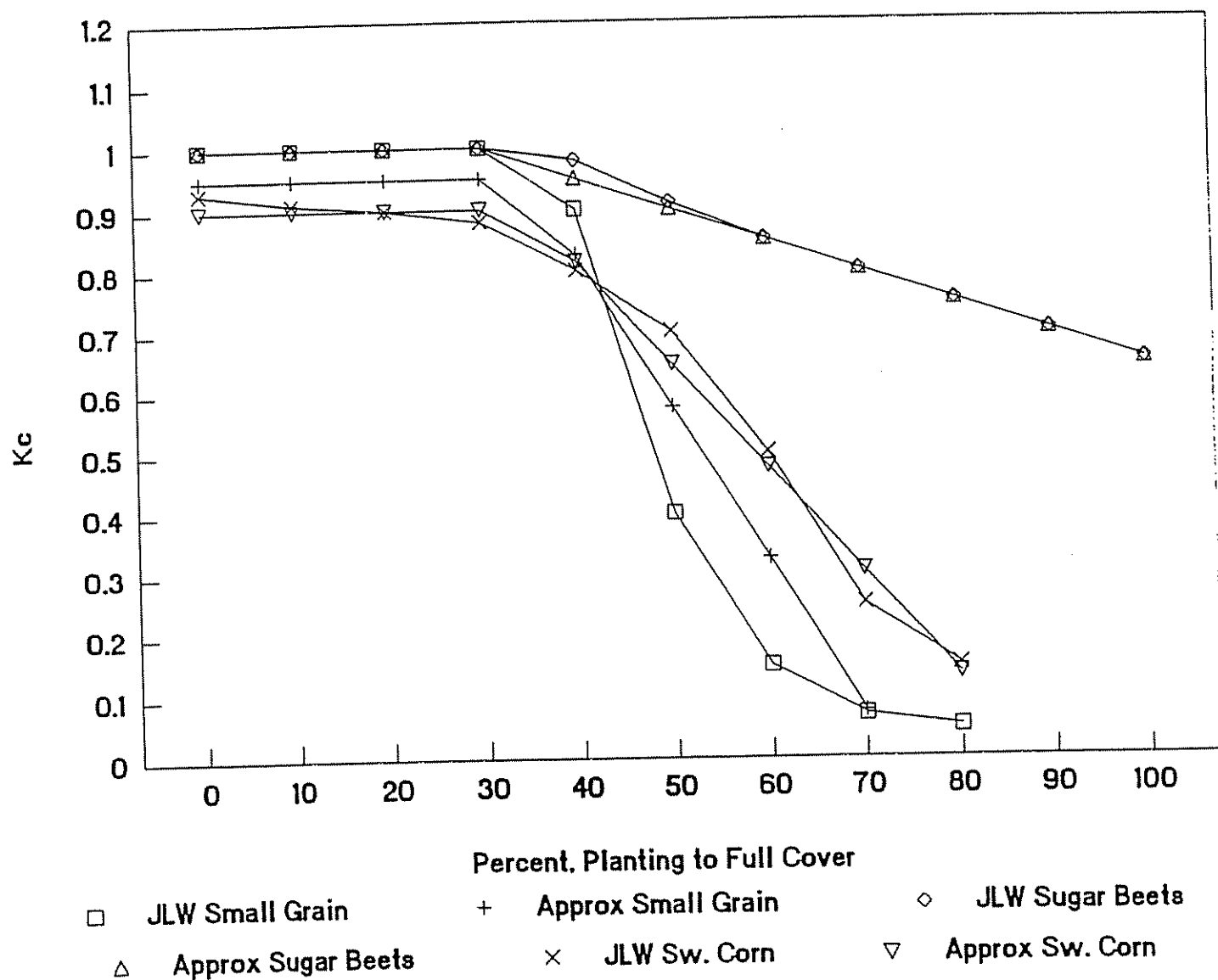# J L WRIGHT'S BASAL CROP COEFFICENTS

## Table 6.6, ASCE Man 70



**Percent, Planting to Full Cover**

- □ JLW Small Grain
- + Approx Small Grain
- ◇ JLW Sugar Beets
- △ Approx Sugar Beets
- × JLW Sw. Corn
- ▽ Approx Sw. Corn

Figure 5. Wright's daily basal crop coefficients for row crops and small grain from full cover to harvest (Wright, Table 6.6, ASCE Manual 70).

# CROP COEFFICIENTS - IID

## JML Kc x 1.2 v. UC Kc
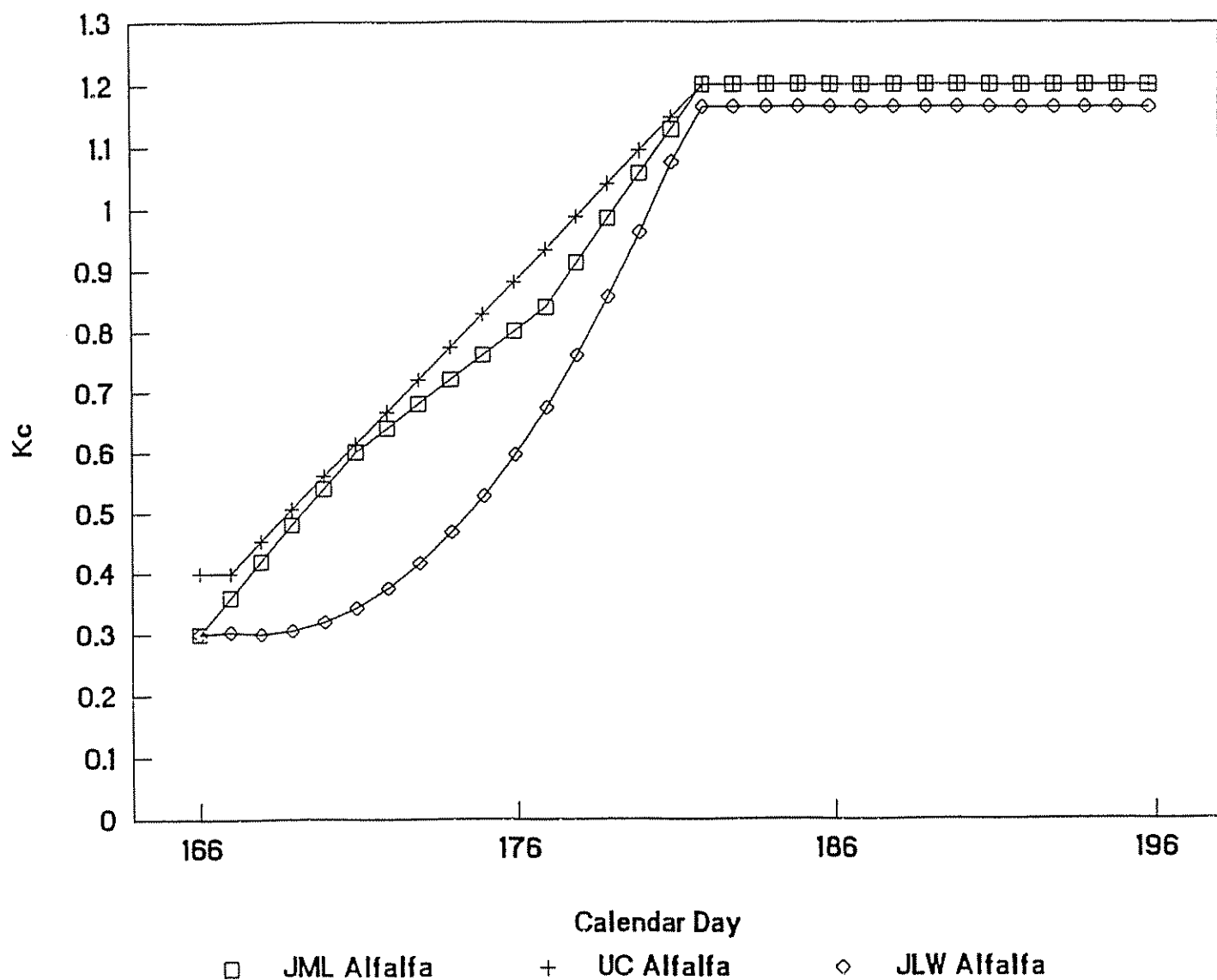


Figure 6. Comparison of UC, JMLord and Wright's daily crop coefficients for alfalfa for a 30-day period from mid-June to mid-July.

<u>Alfalfa Coefficients</u>. The duration of the period between alfalfa cuttings during the summer is about 30 days. A comparison of the UC, JMLord x 1.2 and Wright x 1.2 coefficients for a single period between cutting in mid-summer is shown in Figure 6. Wright's coefficients were based on seven years of daily coefficients determined using a sensitive weighing lysimeter. Clearly, the UC coefficients do not adequately represent the development of leaf area after cutting and use of UC coefficientswould over-estimate alfalfa ET. I decided against using UC-21427 crop coefficients values for quantifying ET values for both IID and CVWD. Generic equations adjusted to fit JMLord's data point were developed for all crops involved except for citrus, dates and grapes.

<u>Citrus Coefficients</u>. Because JMLord's coefficients for citrus seemed to be higher than others being recommended, I elected to use the clean cultivated citrus coefficients developed by Pruitt as printed in Table 6.10, ASCE Manual 70, but I reduced the values by 15 percent (Figure 7).

<u>Grape Coefficients</u>. An assessment of alternative crop coefficients for grapes was made. Three sets of coefficients for grapes are available for specific time periods in California: 1) Grimes and Williams (1990), 2) those suggested by C. M. Burt on 17-Sep-93, and 3) those of Pruitt's from Table 6.10, ASCE Manual 70 (Pruitt et al., 1987). Grimes and Williams coefficients are for Thompson Seedless grapes in the San Joaquin Valley, and those of Pruitt are listed for table grapes. Burt did not specify a grape variety. Pruitt's coefficients, which were for the San Joaquin Valley, were shifted forward to account for the earlier development of grape leaves in the CVWD. Pillsbury (1941) also reported that grapes ripen earlier in this area than in other places. Pruitt's coefficients moved forward and those recommended by C.M Burt are shown in Figure 8.

## Example Application of Procedures

<u>Alfalfa ET</u>. ET was estimated for each crop as illustrated in Figure 9 for alfalfa using the cutting dates suggested in UC Leaflet 21427. Since an available soil water factor was not used, the values of the upper drained limit (field capacity), the lower limit, and management allowed depletion are not important. A graph was used in developing the estimate for each crop because it served as a check on the procedures and crop curve being used.

<u>Row Crop ET</u>. An example of estimating ET for a row crop like cotton is illustrated in Fig. 10. The depth of the root zone varies with the crop coefficient.
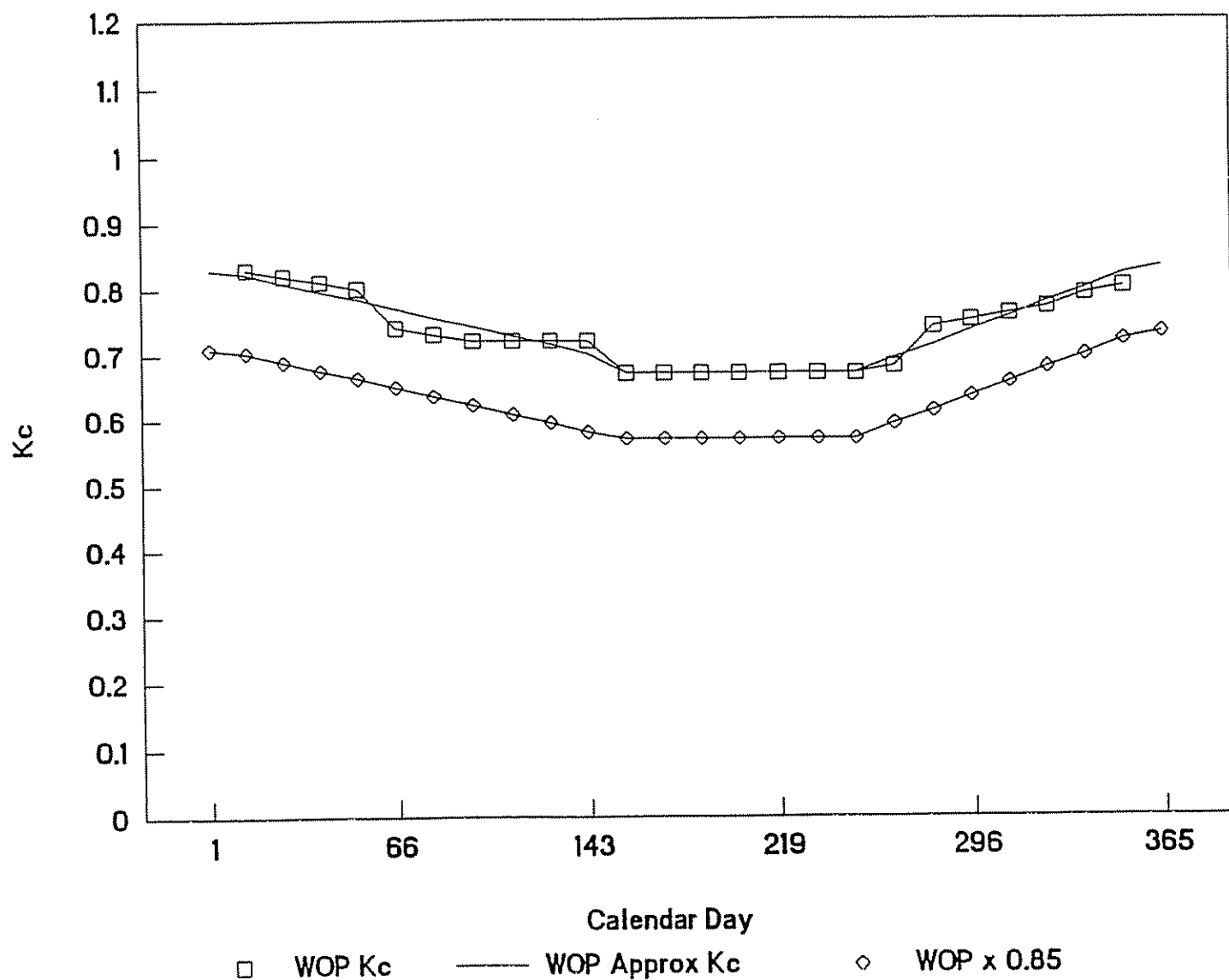
# CITRUS CROP COEFFICIENTS

## FOR USE WITH ETo



Figure 7. Citrus crop coefficients (From Pruitt, 1990).

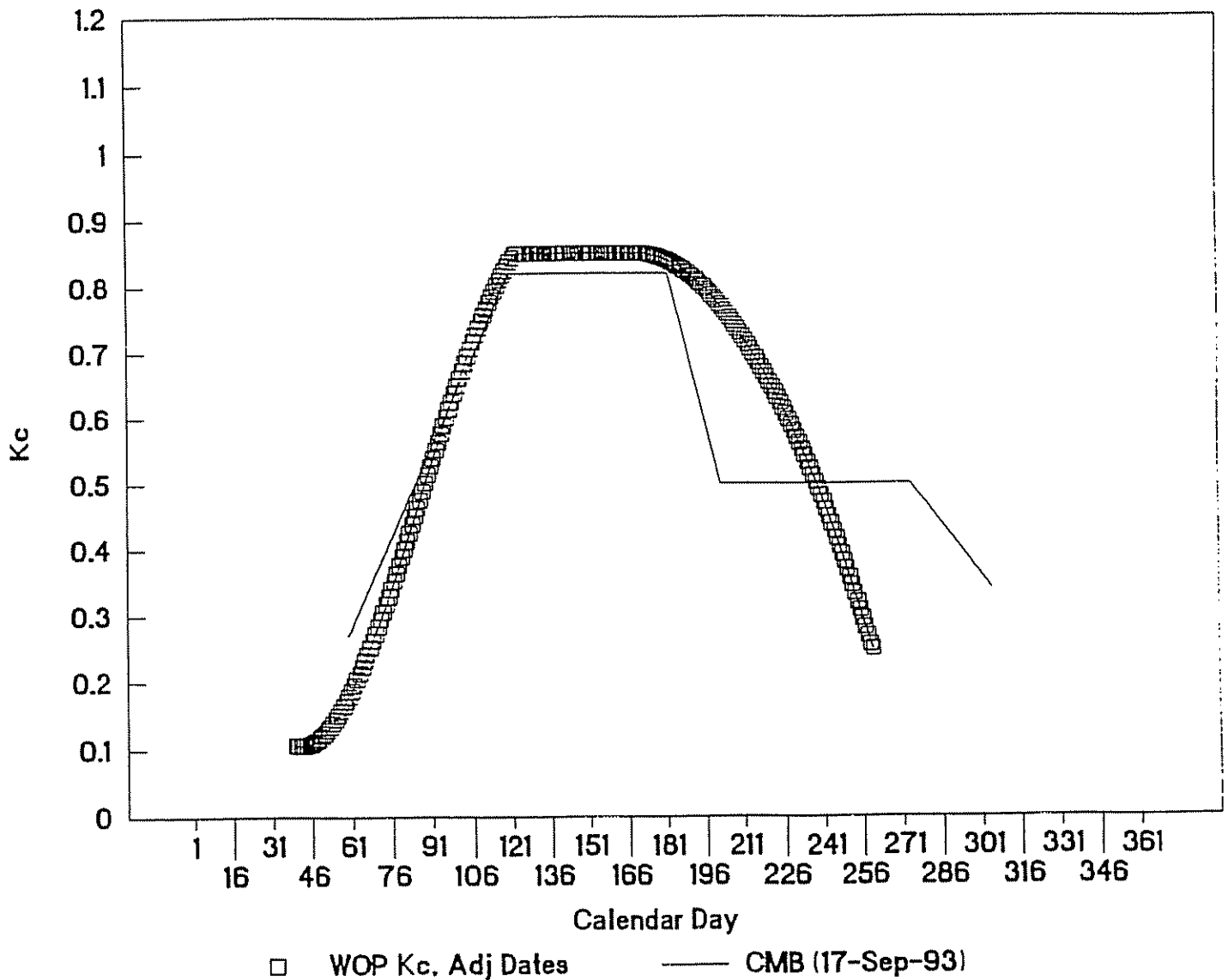# TABLE GRAPE CROP COEFFICIENTS

## FOR USE WITH ETo



Figure 8. Pruitt's adjusted grape coefficients and those recommended by C.M. Burt.

# ESTIMATED ET and SOIL WATER- CVWD
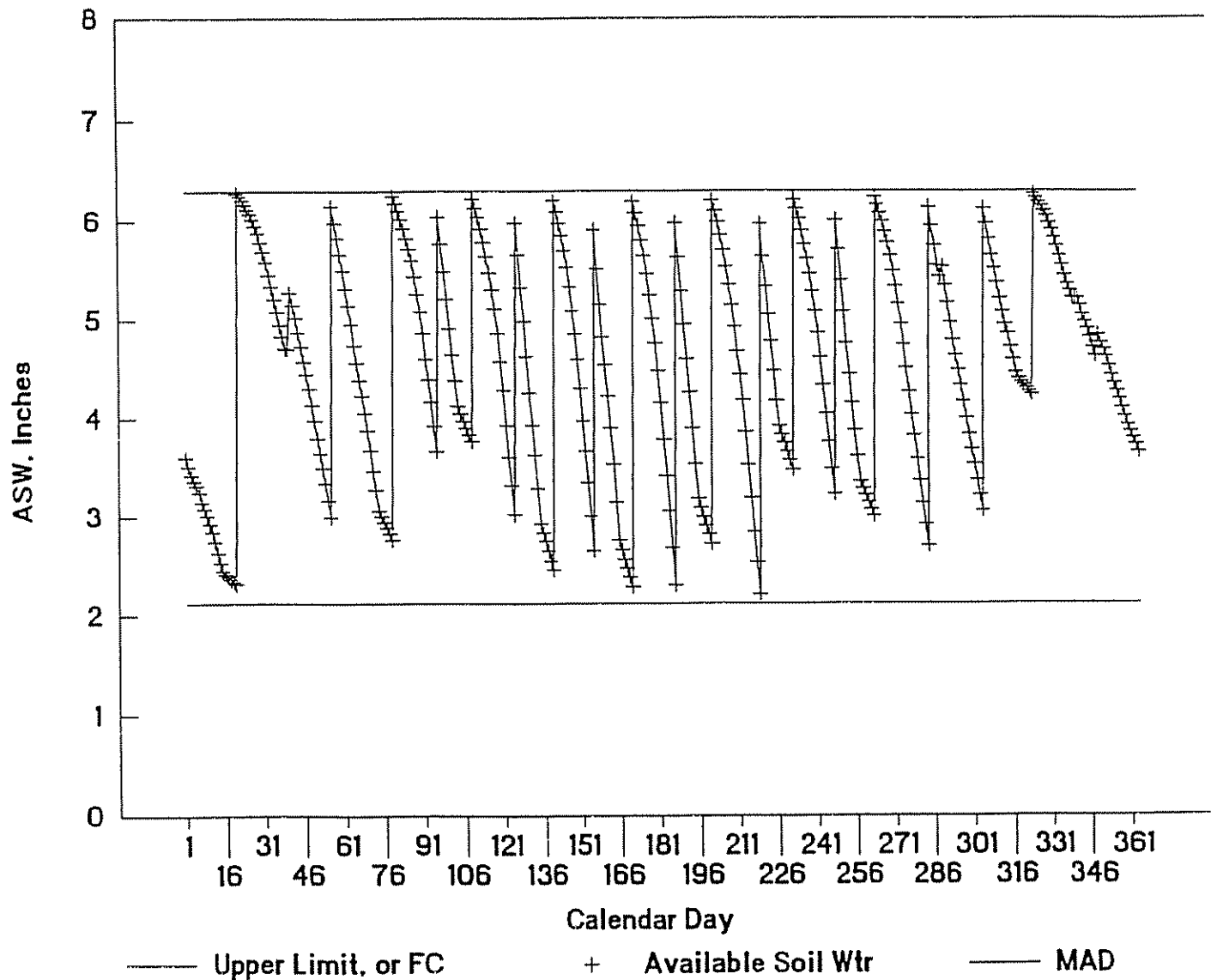
### CROP: ALFALFA, 1987-92



Figure 9. Example crop ET, soil water depletion, and irrigations
for a perennial crop of alfalfa with nine cuttings
scheduled according to UC Leaflet 21247 dates.   A

# ESTIMATED ET and SOIL WATER - CVWD
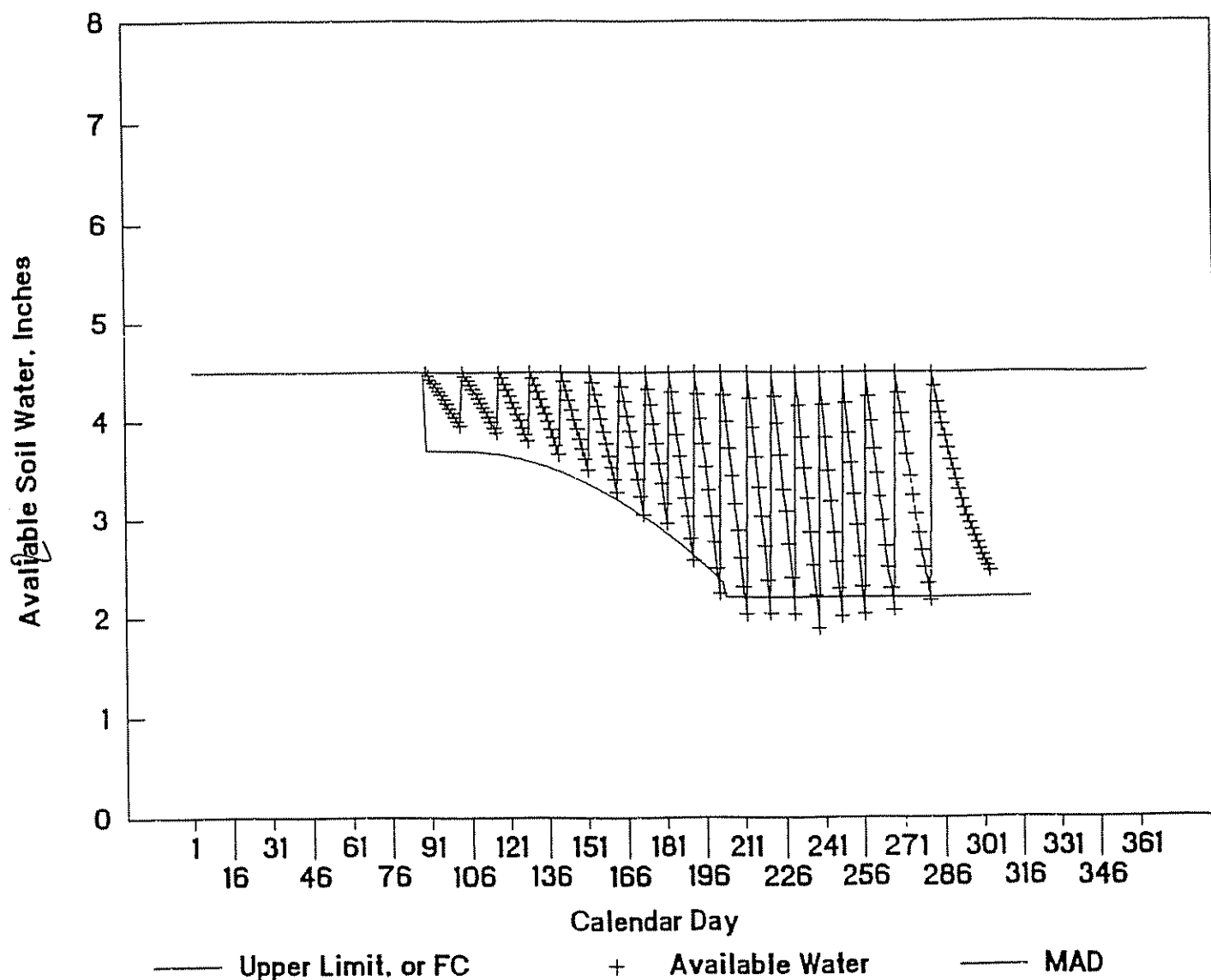
## CROP: COTTON, 1987-92



Fig. 10.  Example crop ET, soil water depletion, and irrigations for an annual crop like cotton.  A variable root depth related to the crop coefficient was used for annual crops.

Dates ET.  Estimated monthly ET for dates using JMLord's coefficients and the ET/solar radiation coefficients given by Jensen and Haise (1963) are presented in Figure 11.  The average of the two methods, which was used for these ET calculations, is also shown.  Pillsbury (1941) noted that if a cover crop, or weeds, were present, transpiration was significantly larger than for cleaned cultivated dates.  The use of either cover crops or interplanting of citrus in the date groves can increase the date grove ET as much as 25 percent.  Therefore, additional information on the condition of the groves will be needed to refine these estimates in Phase II.

## Example Illustration of Crop and Reference ET

An example of mean reference ET and alfalfa ET showing the effects of cuttings on ET rates for the average 1987-1992 climate is presented in Figure 12.  In this case, irrigation dates were synchronized with assumed cuttings. The peaks are the cumulative increases in evaporation following rains.  They are shown as occurring on single day because of the way in which they were calculated.  The actual increases in evaporation would occur over several days in an exponentially decreasing rate.  The total increase in evaporation the total for a given day would not exceed $1.2 ET_o$.

## Adjustment of Alfalfa ET Estimates for Reported Yields

Estimates of alfalfa ET in the CVWD were not based on yield data. It was assumed that infiltration rates were sufficient to meet replace soil water extraction relative to evaporative demands.

## RESULTS OF ANALYSES

## Estimated ET for CVWD using ET x Area Method

Average Annual ET and Farm Irrigation Efficiency.  A summary of estimated average $ET_o$, crop ET, rainfall, E+ (evaporation after rains), Re (effective rainfall), mean $K_c$ for the season, estimated ET and ET values used in the Boyle (Styles, 1993) report is shown in Table 4.  The estimated overall consumptive use coefficient of irrigation water, $CU_c$, expressed as total ET/(net water delivered) for the major crops in the CVWD is shown in Table 5.  Effective rainfall was subtracted from total ET to estimate the fraction of irrigation water consumed.  The uncertainty concerning the amount of pumped water and the amount of deep percolation that recharges the aquifer and is pumped is very large.  A fraction of deep percolation water that is pumped must be subtracted in computing the $CU_c$ as shown otherwise part of the total water delivered is counted twice.
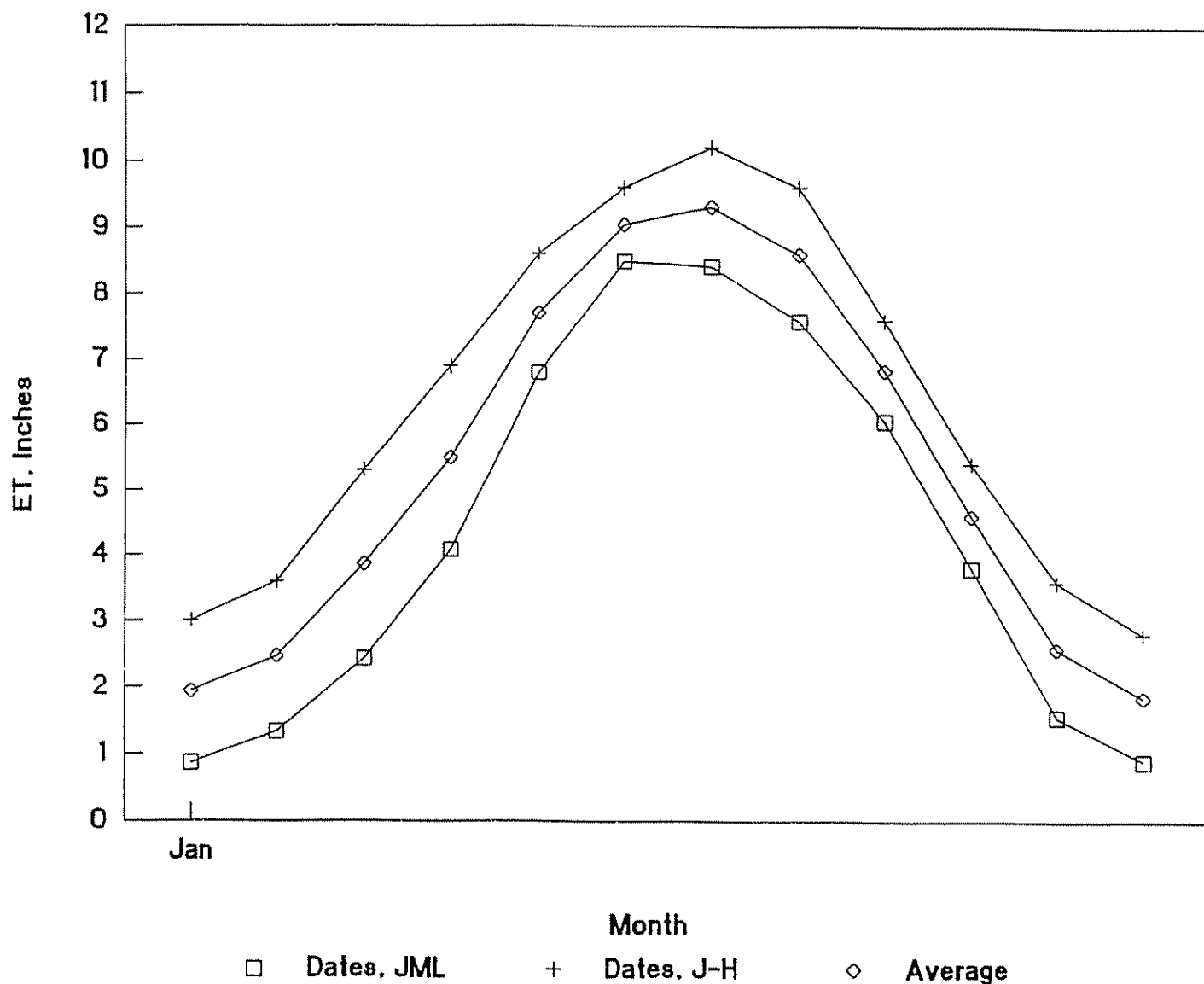
# ESTIMATED MONTHLY ET – CVWD

DATES: 1987-92



Fig. 11. Estimated mean monthly ET for dates using JMLord's coefficients and those of Jensen and Haise (1963).

# CIMIS ETo and ESTIMATED ET - CVWD
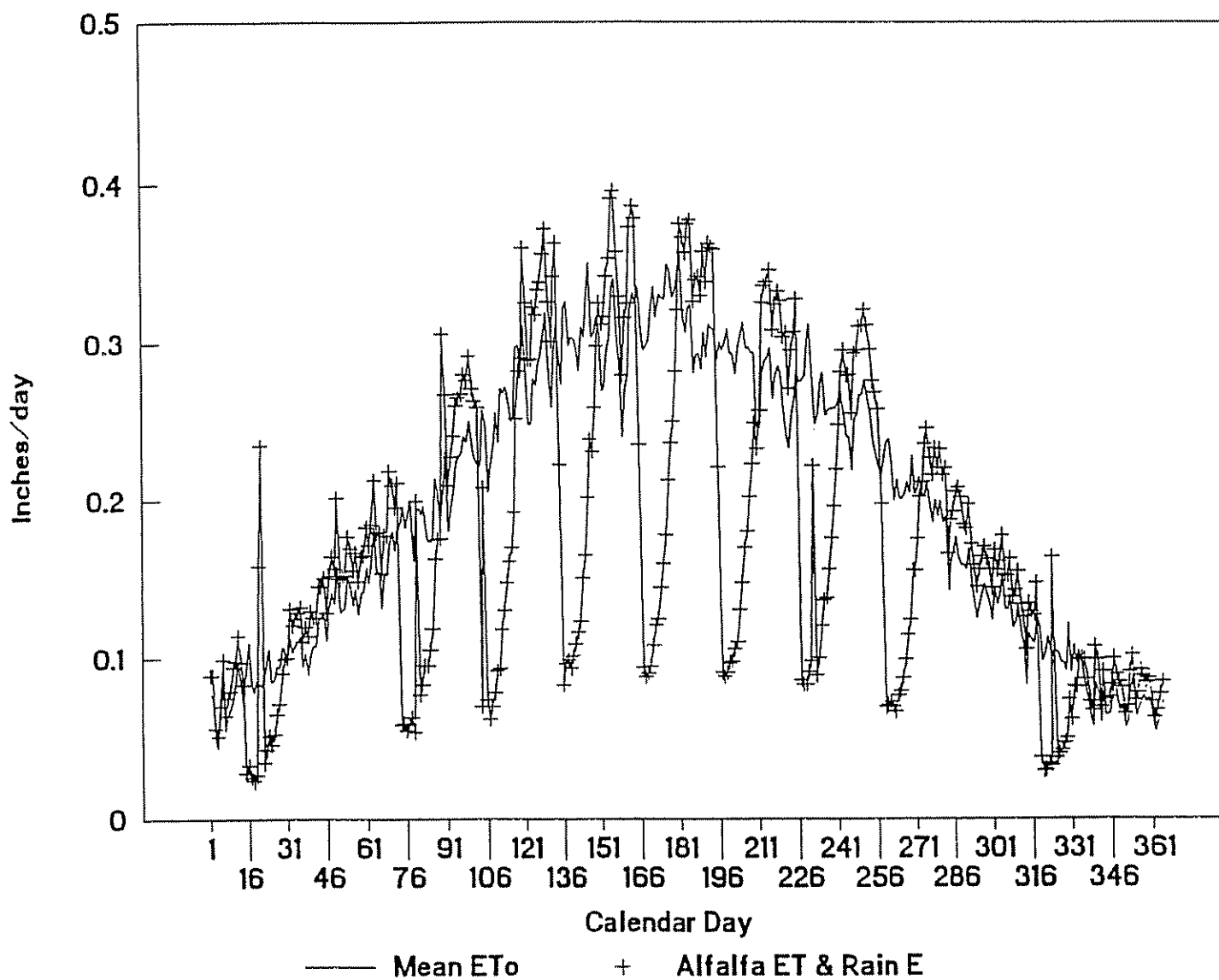
## CROP: ALFALFA, 1987-92



Fig. 12.    Example of mean reference ET, alfalfa ET, and increases
in evaporation following rains for 1987-1992 climate.

Table 4.  Spreadsheet summary of crop planting and harvest dates,
          reference ET, rain, crop ET, rain evaporation (E+),
          effective rainfall,average crop coefficient, sum of ET
          and E+ estimates for CVWD along with ET estimates from
          the 1993 Boyle report.

| Row | 24-Feb-94 | | | | SUMMARY OF ET ESTIMATES FOR CVWD - 1987-1992 | | | | | | | | | \SUMET-CV | CVWD | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 28 | =============================================================================================================================================== |
| 29 | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P |
| 30 | | | | | | SUMMARY | | | | | | | | Boyle (1993) | |
| 31 | | Period | | Foot- | | | | | | | | Sum | | Table 6-4 | (3) |
| 32 | Crop | Start | End | note | ETo | Rain | ET | E+ | Re | Re | Avg Kc | ET+E+ | Footnote | Inches | |
| 33 | --- |
| 34 | FIELD: | | | | In. | In. | In. | In. | In. | % | - - | In. | | | |
| 35 | Alfalfa | 01-Jan | 31-Dec | 1 | 74.3 | 3.1 | 63.9 | 1.6 | 2.7 | 88% | 0.86 | 65.5 | 1 | 70.1 | |
| 36 | Cotton | 31-Mar | 31-Oct | | 57.4 | 0.9 | 38.4 | 0.8 | 0.1 | 11% | 0.67 | 39.2 | | | |
| 37 | Sudan Gr | 01-Apr | 01-Oct | | 39.5 | 0.3 | 35.6 | 0.2 | 0.1 | 33% | 0.90 | 35.8 | | | |
| 38 | Wheat & SmG | 01-Jan | 31-May | | 28.7 | 1.8 | 25.9 | 0.9 | 0.9 | 51% | 0.90 | 26.8 | | | |
| 39 | | | | | | | | | | | | | | | |
| 40 | FRUIT: | | | | | | | | | | | | | | |
| 41 | Citrus | 01-Jan | 31-Dec | | 74.3 | 3.1 | 47.0 | 2.2 | 0.9 | 29% | 0.63 | 49.2 | | 45.0 | |
| 42 | Dates | 01-Jan | 31-Dec | | 74.3 | 3.1 | 64.3 | 2.6 | 0.5 | 16% | 0.87 | 66.9 | 2 | 73.1 | |
| 43 | Grapes | 14-Feb | 20-Sep | | 57.5 | 0.9 | 38.9 | 0.9 | 0.0 | 0% | 0.68 | 39.8 | | 39.9 | |
| 44 | Other T frt | 01-Apr | 15-Nov | No cov | 58.7 | 1.0 | 45.3 | 1.0 | 0.0 | 0% | 0.77 | 46.3 | | | |
| 45 | | | | | | | | | | | | | | | |
| 46 | TRUCK | | | | | | | | | | | | | | |
| 47 | Beans | 01-Oct | 01-Mar | | 16.9 | 2.2 | 12.0 | 0.7 | 1.5 | 68% | 0.71 | 12.7 | | | |
| 48 | Brocolli | 15-Sep | 15-Feb | | 18.5 | 2.3 | 12.3 | 0.9 | 1.4 | 61% | 0.66 | 13.2 | | 14.3 | |
| 49 | Carrots | 30-Sep | 30-Apr | | 30.1 | 2.7 | 20.0 | 1.6 | 1.1 | 41% | 0.66 | 21.6 | | 21.0 | |
| 50 | Corn, sw | 15-Jan | 15-May | | 22.9 | 1.8 | 20.6 | 1.0 | 0.8 | 44% | 0.90 | 21.6 | | | |
| 51 | Lettuce-1 | 31-Aug | 02-Jan | | 18.1 | 1.1 | 16.6 | 0.4 | 0.7 | 64% | 0.92 | 17.0 | | 15.5 | |
| 52 | Onions | 01-Jan | 31-May | | 29.0 | 1.8 | 29.4 | 0.8 | 1.0 | 56% | 1.01 | 30.2 | | | |
| 53 | Peppers | 01-Nov | 31-May | | 34.1 | 2.4 | 30.7 | 1.3 | 1.1 | 46% | 0.90 | 32.0 | | | |
| 54 | Potatoes | 01-Nov | 16-May | | 29.1 | 2.4 | 21.3 | 1.3 | 1.1 | 46% | 0.73 | 22.6 | | | |
| 55 | Squash | 01-Feb | 31-May | | 26.2 | 1.4 | 19.7 | 0.8 | 0.6 | 43% | 0.75 | 20.5 | | | |
| 56 | Watermelon | 01-Jan | 31-May | | 28.7 | 1.8 | 23.0 | 1.1 | 0.7 | 39% | 0.80 | 24.1 | | | |
| 57 | Misc veget | 01-Nov | 30-Jun | | 34.1 | 2.4 | 30.7 | 1.3 | 1.1 | 46% | 0.90 | 32.0 | | | |
| 58 | Nurseries | 01-Nov | 31-Dec | | 13.2 | 1.4 | 12.7 | 0.7 | 0.7 | 50% | 0.96 | 13.4 | | | |
| 59 | Ponds | 01-Jan | 31-Dec | | 74.3 | 3.1 | 72.8 | 0 | 3.1 | 100% | 0.98 | 72.8 | 4 | 87.7 | |
| 60 | --- |

1.  Other cutting dates are: 8/15; 9/15; 11/15; 01/15; 03/15; 04/15; and 05/15.
2.  Average of estimated ET with JMLord coefficients and estimated ET with Jensen and Haise (1963) ET/Rs coefficients.
     Jensen, M.E., and H.R. Haise.  1963. Estimating evapotranspiration from solar radiation. J. Irrig. and Drain. Div.,
     Am. Soc. Civ. Engr. 89(IR4):15-41.
3.  Styles, S. 1993. On-farm Irrigation Efficiency - Special Technical Report, Coachella Valley Water District, April.
4.  Jensen, M.E.  1993.  Report on Evaporation Estimates for IID. 18-Oct, 10 pp + Appendices A & B.

Table 5. Spreadsheet summary of crop acreage, percent of total acreage, annual irrigation water ET rate (crop ET + (E+) - effective rainfall), total irrigation water ET, assigned confidence intervals along with ET estimates from the 1993 Boyle report.

| 74 | | Crop Distribution | | | | | Confidence interval | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 75 | | 81,070 100.0% | Sum | Ac x | Distr· | Crop Normalized | | | | | |
| 76 | Crop | Average | ET+E+-Re | ET-Re | ibution | ET | CV | CV^2 | | Boyle (CVWD) | |
| 77 | ------- | | | | | | | | | | |
| 78 | FIELD CROPS: | Acres Pct | Ac-ft/ac | Ac-ft | % | % | | | | In. | Ft |
| 79 | Alfalfa, forage | 5,029 6.2% | 5.2 | 26,318 | 11.9% | 10% | 0.0059 | 3.53E-05 | | 70.1 | 5.8 |
| 80 | Cotton | 387 0.5% | 3.3 | 1,261 | 0.6% | 10% | 0.0003 | 8.10E-08 | | | |
| 81 | Sudan Gr | 2,940 3.6% | 3.0 | 8,747 | 3.9% | 10% | 0.0020 | 3.90E-06 | | | |
| 82 | Wheat & SmG | 380 0.5% | 2.2 | 820 | 0.4% | 10% | 0.0002 | 3.42E-08 | | | |
| 83 | Subtotal | 8,736 10.8% | | 37,145 | 16.8% | | | | | | |
| 84 | | | | | | | | | | | |
| 85 | FRUIT: | | | | | | | | | | |
| 86 | Citrus | 14,954 18.4% | 4.0 | 60,190 | 27.2% | 10% | 0.0136 | 1.84E-04 | | 45.0 | 3.8 |
| 87 | Dates | 5,769 7.1% | 5.5 | 31,922 | 14.4% | 10% | 0.0072 | 5.19E-05 | | 73.1 | 6.1 |
| 88 | Grapes | 15,376 19.0% | 3.3 | 50,997 | 23.0% | 10% | 0.0115 | 1.32E-04 | | 39.9 | 3.3 |
| 89 | Other T frt | 454 0.6% | 3.9 | 1,752 | 0.8% | 10% | 0.0004 | 1.56E-07 | | | |
| 90 | Subtotal | 36,553 45.1% | | 144,860 | 65.4% | | | | | | |
| 91 | | | | | | | | | | | |
| 92 | TRUCK | | | | | | | | | | |
| 93 | Beans | 900 1.1% | 0.9 | 840 | 0.4% | 10% | 0.0002 | 3.59E-08 | | | |
| 94 | Brocolli | 900 1.1% | 1.0 | 885 | 0.4% | 10% | 0.0002 | 3.99E-08 | | 14.3 | 1.2 |
| 95 | Carrots | 1,500 1.9% | 1.7 | 2,563 | 1.2% | 10% | 0.0006 | 3.34E-07 | | 21.0 | 1.8 |
| 96 | Corn, sw | 4,666 5.8% | 1.7 | 8,088 | 3.6% | 10% | 0.0018 | 3.33E-06 | | | |
| 97 | Lettuce-1 | 3,000 3.7% | 1.4 | 4,075 | 1.8% | 10% | 0.0009 | 8.45E-07 | | 15.5 | 1.3 |
| 98 | Onions | 1,000 1.2% | 2.4 | 2,433 | 1.1% | 10% | 0.0005 | 3.01E-07 | | | |
| 99 | Peppers | 1,000 1.2% | 2.6 | 2,575 | 1.2% | 10% | 0.0006 | 3.38E-07 | | | |
| 100 | Potatoes | 1,000 1.2% | 1.8 | 1,792 | 0.8% | 10% | 0.0004 | 1.63E-07 | | | |
| 101 | Squash | 1,500 1.9% | 1.7 | 2,488 | 1.1% | 10% | 0.0006 | 3.15E-07 | | | |
| 102 | Watermelon | 955 1.2% | 2.0 | 1,862 | 0.8% | 10% | 0.0004 | 1.77E-07 | | | |
| 103 | Misc veget | 900 1.1% | 2.6 | 2,318 | 1.0% | 10% | 0.0005 | 2.73E-07 | | | |
| 104 | Nurseries | 866 1.1% | 1.1 | 917 | 0.4% | 10% | 0.0002 | 4.28E-08 | | | |
| 105 | Subtotal | 18,187 22.4% | | 30,834 | 13.9% | | | | | | |
| 106 | | | | | | | | | | | |
| 107 | MISCELLANEOUS | | | | | | | | | | |
| 108 | Ponds/Reservoirs 1 | 1,424 1.8% | 5.8 | 8,271 | 3.7% | 10% | 0.0019 | 3.48E-06 | | 87.7 | 7.3 |
| 109 | Fallow/Leach 2 | 17,264 21.3% | 0.6 | 477 | 0.2% | 10% | 0.0001 | 1.16E-08 | | | |
| 110 | Subtotal | 18,688 23.1% | | 8,748 | 3.9% | | | | | Range of estimates | |
| 111 | ------- | | | | | | | | | Min | Max ----- |
| 112 | Total | 82,164 101.3% | | 221,587 | 100.0% | | 4.18E-04 | 0.0204 | | 212,528 | 230,647 |
| 113 | | | | | | | Std dev= 4,530 | | | CV = | 2.0% |
| 114 | ------- | | | | | | | | | | |
| 115 | Colorado R. water delivered to agr. users | | | 279,000 | 80% | 5% 0.0201 | 4.03E-04 | 0.0200 | | 267,805 | 290,195 |
| 116 | Pumped water | | | 130,000 | 37% | 40% 0.0748 | 5.59E-03 | 0.0747 | | 110,555 | 149,445 |
| 117 | Less recycled water (15% of above) | 0.15 | (61,350) | -18% | 60%-0.0529 | 2.80E-03 | 0.0529 | | (54,854) | (67,846) |
| 118 | Net total water delivered | | | 347,650 | 100% | | 8.80E-03 | 0.0938 | | 282,431 | 412,869 |
| 119 | Net Confidence interval | | | | | 19% | Std dev= 32,610 | | | CV = | 9.4% |
| 120 | Total variance, ET and net water delivered | | | | | | 0.009216 | 0.0960 | | | |
| 121 | Farm irrigation water consumptive use coeff. | | 63.7% (Excluding LR) | | | | Std dev= 9.6% | | | 44.5% | 82.9% |
| 122 | ------- | | | | | | | | | | |

123  1. Boyle (1993) reported 988 ac of ponds and 436 ac of farm reservoirs, total =    1,424 acres.
124  2. Without actual data, it was assumed that 1 percent of the cropped area was being leached and flooded annually.
125     Evaporation was estimated as 10 percent of the annual average evaporation rate.

Crop acreages summarized from the data provide by JMLord and adjusted for individual crops from other sources, percentage distribution of these acreages, and the estimated confidence interval are presented in Table 5. The Boyle ET values are from the Boyle CVWD report (Styles, 1993). The estimated average ET for CVWD from planting to harvest (excluding preplant-irrigations and evaporation losses) is 221,600 ac-ft with an estimated minimum of 212,500 and a maximum of 230,600 ac-ft.

The estimated average farm irrigation water consumptive use coefficient is 64 percent. The confidence interval ranges was from 45 to 83 percent. Estimated effective rainfall, though small, was subtracted from total ET in these calculations. When adjusted for the leaching requirement, the farm irrigation efficiency was estimated to be 72 percent.

The average farm irrigation water consumptive use coefficient for the CVWD is essentially the same as for the IID. The main difference is the range in the confidence interval between the two districts. The range in the $CU_c$ estimate for the IID is smaller than in the CVWD because of greater uncertainty of the amount of water pumped and the amount of deep percolation that is included in the pumped water.

## Evaluation of Water Delivery v. CIMIS Annual Reference ET

At the time of preparing this report, I did not have the estimates of water delivered to farms for each of the years 1987 through 1992. Therefore, I could not assess the response of Colorado River water orders and pumping to changes in evaporative demand as indicated by annual reference ET.

## SUMMARY AND CONCLUSIONS

ET can be estimated with reasonable accuracy using existing crop coefficients and reference ET measured by CIMIS provided reliable crop acreages are known. Improved data on the range of planting, crop development, and harvest dates and leaf-area development rates will be needed in Phase II to refine ET estimates. Similarly, data on preplant irrigations and/or irrigations to germinate seeds and establish stands will be needed to assess the evaporation losses. Improved data on the volume of water pumped and the proportion of deep percolation that is recycled will be needed also to improve the estimate of the consumptive use coefficient.

# REFERENCES

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**University of California.** Undated. Using Reference Evapotranspiration (ETo) and Crop Coefficients to Estimate Crop Evapotranspiration (ETc) for Agronomic Crops, Grasses, and Vegetable Crops. Coop. Extension, Div. of Agr. and Natural Resources, Leaflet 21427, 12 pp.

## APPENDIX A7-A

## GENERAL PROCEDURES USED AND ASSUMPTIONS FOR ESTIMATING ET

Specific spreadsheet files that were used can be made available if needed. However, they are not fully automated and require some manual adjustments in changing crops. Generic equations AND coefficients for calculating crop coefficients from planting to full cover and days after full cover will be summarized in a separate report in Phase II. Input data and assumptions or conditions assumed in estimating evapotranspiration are summarized below:

INPUT DATA:

**Climate:**
Mean daily CIMIS ETo values were derived from Stations 41, 68 and 87 for the period 1987-1992.

**Rainfall:**
Mean distribution of rainfall events from CIMIS stations 41, 68 and 87.

**Cropping Dates:**
Cropping dates were derived mainly from UC Leaflet 21427 and IID "Schedule of Major Crops".

**Crop Coefficients:**
Mainly daily cropping coefficients were based on generalized curves based on JMLord coefficients multiplied by 1.2 for use with CIMIS reference ET. Several curves were from W.O. Pruitt (ASCE Manual 70, page 127. The shape of the crop curves were based on daily lysimeter-based data from J.L. Wright (ASCE Manual 70).

**Soil:**
Drained upper limit (FC) = 36 percent by volume; Lower Limit = 21 percent by volume. Source: ASCE Manual 70, p. 21.

**Effective Rain:**
Total rainfall minus the increase in evaporation due to rain, E+, was estimated using the equation given on p. 118, ASCE Manual 70. No runoff was assumed for the small events.

**ASSUMPTIONS:**
1. Soil water was assumed adequate and did not limit ET.
2. No increase in evaporation, E+, was added at this time due to wetting following irrigations because irrigation frequency was not known. Frequency is dependent on soil type, depth to the water table and its effects, etc. Data on irrigation frequency collected in Phase II will enable estimating this component of ET.

# APPENDIX 8

## LEACHING REQUIREMENT

Appendix 8:

## Leaching Requirement (LR) Values
### C. Burt

Leaching Requirement Values

An estimate of a single LR value was made for each water district based upon 1992 data. The computation procedure was as follows:

1. Acreage data for 1992 was taken from earlier LR estimate work by JMLord,Inc; these acreages were not reconciled with other TWG acreage estimates.
2. The values for ET of irrigation water were developed by the TWG (Jensen) and are the same as used in other portions of this report.
3. Each crop was weighted by acreage for 1992 and by the ET/acre (in AF) of irrigation water by each crop, for an acreage by Acre-Feet of irrigation water used.

    AF of ETiw = (1992 Acreage) x ETiw
4. Threshold ECe values were based on several literature sources (Doorenbos and Pruitt, 1977; Ayers and Westcot, 1985; Maas, 1990; Rhoades and Loveday, 1990). No consideration was given to adjustments of LR needed for crop rotations.
5. The LR equation is:

$$LR = \frac{ECiw}{5ECe - ECiw}$$

    where

    ECiw = EC of the irrigation water, dS/m
    ECe = Threshold ECe of the specific crop, dS/m

    The ECiw value of 1.15 dS/m utilized in the equation represented the measured salinity of Colorado River water imported to both CVWD and IID during 1992. Farms in CVWD use both Colorado River water and well water. The TWG had very little information regarding well water quality in CVWD, and for Phase I the calculation assumes that well water quality was the same as Colorado River water. This assumption will be refined in Phase II.
6. The LR values for each crop were then weighted by the AF of irrigation water needed for each crop.
7. The weighted LR for the district was computed as:

$$\text{Weighted LR} = \frac{\text{sum of (LR x AF) values}}{\text{Total AF of ET}}$$

Confidence Intervals

The confidence intervals for threshold EC (ECe) and irrigation water EC (ECiw) were estimated to be $\pm$ 20% and $\pm$ 5%, respectively. These values result in a confidence interval for the Leaching Requirement (LR) of $\pm$ 21%. When combined with the confidence interval for district ETc volumes, the resulting confidence intervals for the BenDP are $\pm$ 22% and $\pm$ 24% for IID and CVWD, respectively. The confidence intervals are computed from

$$\frac{S_{LR}^2}{LR^2} \approx \frac{S_{ECe}^2}{ECe^2} + \frac{S_{ECiw}^2}{ECiw^2}$$

$$\frac{S_{BenDP}^2}{BenDP^2} \approx \frac{S_{LR}^2}{LR^2} + \frac{S_{ETc}^2}{ETc^2}$$

| | Estimates of district LR's. | | | | | |
|---|---|---|---|---|---|---|
| | ECw = 1.15 dS/m | | | | | |
| | | | | | | |
| | | | | | | |
| **CVWD** | | | | | | |
| Crop | 1992 Acreage | ETiw, ft | AF of ETiw | Thresh ECe | LR | LR x AF |
| Alfalfa, forage | 2130 | 5.2 | 11076 | 2.0 | 0.13 | 1439 |
| Cotton | 387 | 3.3 | 1277 | 7.7 | 0.03 | 39 |
| Sudan grassw | 2940 | 3.0 | 8820 | 2.8 | 0.09 | 789 |
| Irrig Past | 1555 | 5.2 | 8086 | 2.5 | 0.10 | 819 |
| Wheat & Sm G | 380 | 2.2 | 836 | 6.0 | 0.04 | 33 |
| Turf | 500 | 5.2 | 2600 | 6.0 | 0.04 | 104 |
| Citrus | 13094 | 4.0 | 52376 | 1.7 | 0.16 | 8195 |
| Dates | 5689 | 5.5 | 31290 | 4.0 | 0.06 | 1909 |
| Grapes | 12008 | 3.3 | 39626 | 1.5 | 0.18 | 7176 |
| Other T. fruit | 454 | 3.9 | 1771 | 1.5 | 0.18 | 321 |
| Beans | 892 | 0.9 | 803 | 1.0 | 0.30 | 240 |
| Brocolli | 810 | 1.0 | 810 | 2.8 | 0.09 | 72 |
| Carrots | 1140 | 1.7 | 1938 | 1.0 | 0.30 | 579 |
| Corn, sw | 4582 | 1.7 | 7789 | 1.7 | 0.16 | 1219 |
| Lettuce | 2596 | 1.4 | 3634 | 1.3 | 0.21 | 781 |
| Onions | 609 | 2.4 | 1462 | 1.2 | 0.24 | 347 |
| Peppers | 1245 | 2.6 | 3237 | 1.5 | 0.18 | 586 |
| Potatoes | 870 | 1.8 | 1566 | 1.7 | 0.16 | 245 |
| Squash | 647 | 1.7 | 1100 | 3.2 | 0.08 | 85 |
| Watermelon | 724 | 1.4 | 1014 | 2.2 | 0.12 | 118 |
| Misc. veg. | 3256 | 2.2 | 7163 | 1.8 | 0.15 | 1049 |
| Nurseries | 790 | 1.1 | 869 | 1.5 | 0.18 | 157 |
| | | Total AF of ET= | 189143 | | | 26304 |
| | | Weighted LR by AF = | | | 0.14 | |
| **IID** | | | | | | |
| Crop | Ac 1992 | ETiw, ft | AF of ETiw | Thresh ECe | LR | LR x AF |
| Alfalfa, all | 193304 | 4.2 | 811877 | 2.0 | 0.13 | 105498 |
| Cotton | 4227 | 3.2 | 13526 | 7.7 | 0.03 | 416 |
| Grasses, all | 35557 | 3.7 | 131561 | 6.0 | 0.04 | 5244 |
| Sorghum/suda | 53668 | 3.7 | 198572 | 2.8 | 0.09 | 17771 |
| Sugar beets | 39703 | 2.8 | 111168 | 7.0 | 0.03 | 3777 |
| Wheat & Sm G | 81106 | 2.0 | 162212 | 6.0 | 0.04 | 6466 |
| Citrus | 2609 | 3.9 | 10175 | 1.7 | 0.16 | 1592 |
| Fruit | 408 | 3.7 | 1510 | 1.5 | 0.18 | 273 |
| Jojoba | 2117 | 3.0 | 6351 | 4.0 | 0.06 | 387 |
| Asparagus | 6466 | 5.1 | 32977 | 4.1 | 0.06 | 1960 |
| Broccoli | 8922 | 1.1 | 9814 | 2.8 | 0.09 | 878 |
| Cantaloupe/H | 12748 | 1.5 | 19122 | 2.2 | 0.12 | 2233 |
| Carrots | 15724 | 1.7 | 26731 | 1.0 | 0.30 | 7985 |
| Cauliflower | 6288 | 0.8 | 5030 | 2.8 | 0.09 | 450 |
| Corn, all | 4008 | 1.7 | 6814 | 1.7 | 0.16 | 1066 |
| Lettuce | 23141 | 1.4 | 32397 | 1.3 | 0.21 | 6964 |
| Onions, Gar | 13340 | 2.7 | 36018 | 1.2 | 0.24 | 8540 |
| Tomato | 3483 | 2.2 | 7663 | 2.5 | 0.10 | 776 |
| Watermelon | 2485 | 1.3 | 3231 | 2.2 | 0.12 | 377 |
| Misc. veg. | 5802 | 2.2 | 12764 | 1.8 | 0.15 | 1870 |
| Nurseries | 337 | 2.0 | 674 | 1.5 | 0.18 | 122 |
| | | Total AF of ET= | 1640186 | | | 174647 |
| | | Weighted LR by AF = | | | 0.11 | |

# APPENDIX 9

## PERFORMANCE PARAMETER CALCULATIONS

APPENDIX 9

## Performance Parameter Calculations
### prepared for the TWG by
### A.J. Clemmens


## INTRODUCTION

The performance parameters examined are defined in Section 1 of this report.
These include the District Distribution Efficiency, District Irrigation
Efficiency, Average Farm Irrigation Efficiency, and Consumptive Use
Coefficient. Not enough information was available to estimate Irrigation
Sagacity.

Additional terms defined include Standard Deviation (S), Coefficient of
Variation (C), and Confidence Interval (CI, ± 2S) with associated lower and
upper bounds.

It should be noted that the expected value of a ratio is not always the value
computed by simple division. Statistically ratios are difficult to evaluate.
The confidence intervals are not known very precisely. The values shown here
are conservative (i.e., likely wider than necessary). See Appendix 1 for
details on the calculation of confidence intervals for ratios, as well as
products and sums.

The calculation of confidence intervals for total beneficial uses is
complicated in that ET is included in all three beneficial uses that are added
together. This is handled in a special way as described in Appendix 1.

The values used in the various efficiency calculations are discussed in
Section 3 of the main report.


## CVWD

The calculation of CVWD performance parameter confidence intervals is shown in
Table A9-1 for 1987. The confidence interval for District Delivery Efficiency
is unrealistic since it spans 100%, and indicates one problem in dealing with
ratios. As state above, the confidence intervals for IE and CUC are
conservative. Table A9-2 provides the confidence intervals for the various
performance parameters for the period 1987 to 1992. No significant trends
over this time interval is apparent.

Values given in Tables A9-1 and A9-2 were taken from tables in Section 3 of
the Phase I report and other appendices as noted. Water supply numbers for
CVWD can be found in Table 3-5 and in Appendix 2. Beneficial uses are given
in Table 3-6 and Appendices 2, 7 and 8. Weather-based estimates of crop ET
were used. Other evaporative losses and consumtive uses are discuessed in
Appendix 2.

The water balance used to determine groundwater pumping has an error.
Effective precipitation was inadvertently left out. When added back in,
groundwater pumping (and thus *Gross Farm Irrigation Water* and *Net District
Supply*) would increase about 5,000 ac-ft/yr on average. The range in
calculated efficiencies would decrease about 1% on average. The numbers here
are consistent with the main body of the report, which includes this error.

A9-1

Table A9-1. Coachella Valley Water District performance parameter calculations for 1987.

| | Volume (1,000 ac-ft) | CI (% of value) | C* | C² |
|---|---|---|---|---|
| Colorado Water Delivered to Farms | 282 | ±5% | 0.0250 | 0.000625 |
| Colorado Water Delivered to District | 286 | ±5% | 0.0243 | 0.000593 |
| District Delivery Efficiency | | ±7% | 0.0349 | 0.001218 |
| Confidence Interval | | | | |
| Lower bound 92% | | | | |
| Upper bound 106% | | | | |
| S ±3% | | | | |
| | | | | |
| Irr. Water Crop Consum. Use, $ET_{iw}$ | 225 | ±12% | 0.0610 | 0.003721 |
| Beneficial Leaching | 37 | ±24% | 0.0165 | 0.000273 |
| Other Ben. uses | 4 | ±100% | 0.0085 | 0.000071 |
| (Total BU as fraction of $ET_{iw}$) 1.183 | | | 0.0186 | 0.000344 |
| Total Benificial uses (sum) | 266 | ±13% | 0.0638 | 0.004065 |
| | | | | |
| Total Benificial uses | 266 | ±13% | 0.0638 | 0.004065 |
| Net district Supply | 376 | ±12% | 0.0605 | 0.003655 |
| Distict Irrigation Efficiency | | ±18% | 0.0879 | 0.007720 |
| Confidence Interval | | | | |
| Lower bound 58% | | | | |
| Upper bound 83% | | | | |
| S ±6% | | | | |
| | | | | |
| Total Benificial uses | 266 | ±13% | 0.0638 | 0.004065 |
| Gross farm irrig. water | 403 | ±12% | 0.0614 | 0.003764 |
| Average Farm Irrigation Efficiency | | ±18% | 0.0885 | 0.007829 |
| Confidence Interval | | | | |
| Lower bound 54% | | | | |
| Upper bound 78% | | | | |
| S ±6% | | | | |
| | | | | |
| Canal and Reservoir Evaporation | 2 | ±20% | 0.0007 | 0.000000 |
| Evap. from Drains, Rivers & Phreat. | 40 | ±50% | 0.0362 | 0.001309 |
| Irr. Water Crop Consum. Use | 225 | ±12% | 0.0497 | 0.002466 |
| Sprinkler Evaporation | 2 | ±20% | 0.0008 | 0.000001 |
| Farm Pond Evaporation | 3 | ±20% | 0.0010 | 0.000001 |
| Other farm evaporative losses | 5 | ±100% | 0.0081 | 0.000066 |
| Total consumption (sum) | 276 | ±12% | 0.0620 | 0.003844 |
| | | | | |
| Total consumption | 276 | ±12% | 0.0620 | 0.003844 |
| Net district Supply | 376 | ±12% | 0.0605 | 0.003655 |
| Consumptive Use Coefficient | | ±17% | 0.0866 | 0.007499 |
| Confidence Interval | | | | |
| Lower bound 61% | | | | |
| Upper bound 86% | | | | |
| S ±6% | | | | |

*Coefficient of Variation, C, is normalized for addition and subtraction (sums). For Beneficial uses, C is computed in two steps (see Appendix 1).

Table A9-3. Imperial Irrigation District performance parameter calculations for 1987.

| | Volume (1,000 ac-ft) | CI (% of value) | $C^{\bullet}$ | $C^2$ |
|---|---|---|---|---|
| Colorado Water Delivered to Farms | 2,322 | ±5% | 0.0250 | 0.000625 |
| Net district Supply | 2,602 | ±4% | 0.0182 | 0.000331 |
| District Delivery Efficiency | | ±6% | 0.0309 | 0.000956 |
|   Confidence Interval | | | | |
|       Lower bound   84% | | | | |
|       Upper bound   95% | | | | |
|       S   ±3% | | | | |
| Deep Percolation | 245 | ±77% | 0.3850 | 0.148193 |
| Effectiveness of Deep Perc. | 0.8 | ±20% | 0.1000 | 0.010000 |
| Effective leaching (unused) | 196 | ±80% | 0.3977 | 0.158193 |
| Irr. Water Crop Consum. Use, $ET_{iw}$ | 1,674 | ±7% | 0.0372 | 0.001381 |
| Beneficial Leaching | 207 | ±22% | 0.0119 | 0.000141 |
| Other Beneficial uses | 33 | ±100% | 0.0087 | 0.000076 |
|   (Total BU as fraction of $ET_{iw}$)  1.144 | | | 0.0148 | 0.000218 |
| Total Benificial uses (sum) | 1,915 | ±8% | 0.0400 | 0.001599 |
| Total BU | 1,915 | ±8% | 0.0400 | 0.001599 |
| Net district Supply | 2,602 | ±4% | 0.0182 | 0.000331 |
| Distict Irrigation Efficiency | | ±9% | 0.0439 | 0.001930 |
|   Confidence Interval | | | | |
|       Lower bound   67% | | | | |
|       Upper bound   80% | | | | |
|       S   ±3% | | | | |
| Total BU | 1,915 | ±8% | 0.0400 | 0.001599 |
| Water Delivered to Ag users | 2,322 | ±5% | 0.0250 | 0.000625 |
| Average Farm Irrigation Efficiency | | ±9% | 0.0472 | 0.002224 |
|   Confidence Interval | | | | |
|       Lower bound   75% | | | | |
|       Upper bound   90% | | | | |
|       S   ±4% | | | | |
| Canal and Reservoir Evaporation | 24 | ±20% | 0.0013 | 0.000002 |
| Evap. from Drains, Rivers & Phreat. | 87 | ±20% | 0.0048 | 0.000023 |
| Sprinkler Evaporation | 9 | ±25% | 0.0006 | 0.000000 |
| Farm Pond Evaporation | 0 | ±25% | 0.0000 | 0.000000 |
| Other farm evaporative losses | 33 | ±100% | 0.0090 | 0.000081 |
| Irr. Water Crop Consum. Use | 1,674 | ±7% | 0.0340 | 0.001159 |
| Total consumption (sum) | 1,828 | ±7% | 0.0356 | 0.001266 |
| Total consumption | 1,828 | ±7% | 0.0356 | 0.001266 |
| Net district Supply | 2,602 | ±4% | 0.0182 | 0.000331 |
| Consumptive Use Coefficient | | ±8% | 0.0400 | 0.001597 |
|   Confidence Interval | | | | |
|       Lower bound   65% | | | | |
|       Upper bound   76% | | | | |
|       S   ±3% | | | | |

$^{\bullet}$Coefficient of Variation, C, is normalized for addition and subtraction (sums). For Beneficial uses, C is computed in two steps (see Appendix 1).

# APPENDIX 10

GROUNDWATER/AQUIFER INFORMATION
FOR THE LOWER COACHELLA VALLEY

<div style="border:1px solid black">

# Groundwater/Aquifer Information
# for the
# Lower Coachella Valley

</div>

C. Burt - rev. 1/94

## Introduction

The aquifer and groundwater conditions of the Lower Coachella Valley (south of Point Happy) are not well understood. I have tried to organize information which helps to shed light on some of these topics. The information summarized in this report to the TWG should assist in making decisions regarding future data collection.

## Background and Geology

The USGS (1991) has listed the wells in a fairly extensive data base regarding water depth and quality for the CVWD service area. However, the majority of these wells are in the Upper Coachella-Valley rather than the Lower Coachella Valley. Several groundwater models and studies (Tyley, 1971; Mallory et. al, 1980; USGS, 1991) have been developed/conducted for the Upper Coachella Valley, but no results have been published for the Lower Valley.

## Subsurface Flow into the Lower Coachella Valley

A study by the USGS in 1971 (Analog Model Study of the Ground-Water Basin of the Upper Coachella Valley California, by S. J. Tyley) indicated that the subsurface inflow to the lower valley (beginning at Point Happy) from the upper valley changed from 50,000 AF in 1936 to **25,000 AF in 1967**. The change was due to rising water levels in the lower valley.

A later study by the USGS (Water Resources Inv. Report 91-4142, Evaluation of a Ground-Water Flow and Transport Model of the Upper Coachella Valley, CA) estimated the inflow to the lower valley from the upper valley at **7,000 AF in 1986**.

## Subsurface Outflow to Salton Sea

A report by CVWD prepared by Bechtel Corporation (Comprehensive Water Resources Mgmt. Plan, 1967) estimated <u>33,000 AF subsurface outflow to the Sea</u>. No justification was seen for this estimate.

## Pumping Depths

<u>Conversation with local driller</u>. A visit was made on Sept. 31, 1993 with Karl Bockler, Sales Engineer of the McCalla Division of Layne-Western Co. in Coachella. His address is:

> 53-381 Hwy 111
> Coachella, CA 92236
> phone: 619-398-8887

Karl has worked in the area for a few years and does "a lot" of well pump evaluations. McCalla drills wells and also replaces old pumps. Here are the key comments which he made:

- One can drill 2 wells 50 feet apart and one will produce 500 GPM and the next 5 GPM. The differences in stratification are tremendous.
- If the water table is within 50' of the surface, they must install a 200' liner (sanitary seal). They do this by pumping 200' of concrete slurry around the casing.
- The average depth of domestic wells is 400-500'
- A typical pumping plant efficiency for wells is 60% - 70%. This includes both motor and impeller.
- Most agricultural irrigation wells have 500-600 GPM.
- Pumping water levels vary greatly in the valley, from about 10' or so to about 170'. The drawdown (part of the pumping water level) depends upon the casing, flow rate, and location.
- Karl provided the information in Table 1 about some recent pumps they have installed:

Table 1. TDH and GPM requirements for new pumps by McCalla.

| Location | Static (ft) | Pumping | GPM |
|---|---|---|---|
| Ave 41, Wash .5 (North of Indio) | 125 | 135 | 50 |
| Ave. 55, Filmore (E. of Thermal) | 11' | | |
| Ave. 71, Hayes (V. near S. Sea, E side) | 2' | 100' | 50 |
| Ave 82, Buchanon SW side, above CVWD distrib. pipelines | 120' | 131' | 400 |
| Ave 83, Johnson (fish farm on W side of SS) | 83 | 95 | 350 |

- Karl also displayed drilling logs from a variety of recent wells. The information is shown in Table 2 below.

Table 2. Recent logs of drilling by McCalla.

| T | R | Sec | Static, ft | GPM | Dwdn. ft | Test hrs |
|---|---|---|---|---|---|---|
| 5S | 7E | 7 (NW of Indio) | 125 | 50 | 10 | 4 |
| 8S | 8E | 10 SW, near SS, above dis. syst. | 189 | 1000 | 19 | 22 |
| 7S | 8E | 24 SW, near SS, E of Hwy 86 | 68 | 4000 | 101 | 8 |
| 7S | 8E | 24 | 68 | 4000 | 99 | 8 |
| 7S | 8E | 25 | 30 | 3400 | 139 | 24 |
| 7S | 8E | 25 | 15 | 3000 | 140 | 24 |
| 7S | 8E | 22 South center, near Hwy 86 & ave 70. | 71 | 2000 | 137 | 6 |
| 6S | 8E | 24 3 mi E of Thermal | 71 | 2000 | 66 | 12 |
| 7S | 7E | 3 Far W & Center Above dist. syst. | 125 | 250 | 85 | 4 |
| 6S | 7E | 29 near L. Cahuilla | 130 | 3000 | 12.5 | 5 |
| 7S | 7E | 2 N. of L. Cahuilla by 2 mi; W of canal ????? | 23 | | | |
| 6S | 8E | 14 1 mi. NE of Thermal | 8 | 250 | 50 | 8 |

City of Indio. The City of Indio maintains records on pumping water levels in its wells. The following is a summary of their data.

Table 3. Water levels (ft) and flows in wells of the City of Indio.

| Well # | Date | Static | Dwdn | GPM |
|--------|------|--------|------|-----|
| 1A | July 56 | 32 | 15.3 | 1500 |
| | Sept. 76 | 19 | 22 | 2000 |
| | April 85 | 25 | 5 | 1965 |
| | May 89 | 31 | 19 | 1900 |
| | Feb 92 | 32 | 16 | 1800 |
| | May 93 | 38 | 10 | 1800 |
| 1B | Dec 76 | 20 | 16 | 1000 |
| | June 80 | 27 | 14 | 1000 |
| | Feb 86 | 27 | 14 | 1150 |
| | Dec 92 | 37 | 10 | 1250 |
| | May 93 | 37 | 4 | 1000 |
| 1C | Feb 70 | 19 | 53 | 2000 |
| | Feb 86 | 41 | 24 | 1750 |
| | Dec 89 | 56 | 30 | 1800 |
| | Feb 92 | 57 | 28 | 2000 |
| | May 93 | 52 | 32 | 1850 |
| 2A | Dec. 76 | 39 | 31 | 1000 |
| | May 82 | 50 | 24.5 | 1000 |
| | July 86 | 68 | 9 | 975 |
| | May 87 | 64 | 11 | 925 |
| | May 90 | 66 | ? | ? |
| 2B | Dec 76 | 39 | 13 | 1000 |
| | April 85 | 60 | 11 | 1275 |
| | May 89 | 83 | 23 | 1800 |
| | April 92 | 73 | 30 | 1800 |
| | May 93 | 90 | 21 | 1775 |
| 2C | May 75 | 45 | 23 | 1700 |
| | May 85 | 63 | 17 | 1600 |
| | April 92 | 73 | 29 | 2475 |
| | May 93 | 93 | 26 | 2275 |
| 3A | Dec. 76 | 44 | 12 | 1500 |
| | Aug 86 | 86 | 14 | 1300 |
| | June 90 | 83 | 12 | 1500 |
| | May 93 | 93 | 17 | 1650 |
| 3B | June 80 | 62 | 21 | 1950 |
| | June 86 | 90 | 18 | 1750 |
| | May 89 | 88 | 29 | 2025 |
| 3C | April 75 | 41 | 35 | 2000 |
| | April 86 | 78 | 17 | 2000 |
| | June 89 | 79 | 32 | 1600 |
| | Jan 90 | 79 | 18 | 1800 |
| | July 91 | 96 | 41 | 2100 |
| 4A | June 86 | 74 | 24 | 1650 |
| | Aug 92 | 118 | 17 | 1600 |
| 4B | April 92 | 94 | 6 | 800 |
| | Aug 92 | 98 | 30 | 1600 |

CVWD Well Monitoring. CVWD has "Depth to Water" measurements on a number of wells throughout CVWD. The measurements may be a mix of static and pumping water levels, although most may be static. It is unclear how many of these measurements are made and recorded by CVWD. The following table summarizes the most recent water levels from a total of 18 field notes which Robert Robinson of CVWD provided on Oct. 1, 1993. Seven of the locations, appearing with strike-throughs, are well outside of the main irrigated area.

Table 4. CVWD well monitoring values provided by R. Robinson of CVWD.

| Well location | GW depth, feet. | Notes, test date |
|---|---|---|
| ~~NW corner Monterey & Ave. 44 Sec. 17, T5S, R6E~~ | ~~166~~ | ~~200 HP; 5/92~~ |
| ~~NE corner Monterey & Ave. 44 Sec. 17, T5S, R6E~~ | ~~160~~ | ~~30 HP, 3/92~~ |
| ~~SW corner of Cook St. & Hwy 111 Sec. 21, T5S, R6E~~ | ~~189~~ | ~~40 HP, 10/92~~ |
| ~~NW corner of Cook St. & Hwy 111 Sec. 21, T5S, R6E~~ | ~~172~~ | ~~25 HP, 4/91~~ |
| ~~near Frank Sinatra Rd. Sec. 3, T5S, R6E~~ | ~~160~~ | ~~9/92~~ |
| ~~NW of Cook St. & Ave. 44 Sec. 16, T5S, R6E~~ | ~~143~~ | ~~10 HP, 3/92~~ |
| W of Hwy 86 & Ave. 81 Sec. 24, T8S, R8E | 115 | 8/93 |
| ~~Between Polk & Tyler on Ave. 77; Sec. 9, T8S, R8E~~ | ~~241~~ | ~~75 HP, 8/93~~ |
| N. of Ave. 70, between Fillmore & Polk; Sec. 22, T7S, R8E | 65 | 40 HP, 9/93 |
| On Ave. 75, E of Polk St.; Sec. 3, T8S, R8E | 126 | 50 HP, 8/93 |
| Ave. 71, Between Tyler and Harrison; Sec. 29, T7S, R8E | 65 | 100 HP, 8/93 |
| NE cor. of Hwy 86/ Ave. 66; Sec. 8, T7S, R8E | 71 | 8/93 |
| Ave. 68, between Van Buren & Harrison; Sec. 18, T7S, R8E | 180 | 150 HP; 8/93; ; water turned on at time of meas. |
| SE corner of Ave. 56 & Van Buren; Sec. 19, T6S, R8E | 42 | 8/93 |
| SE corner of Ave. 50/Polk; Sec. 3, T6S, R8E | 27 | 8/93 |
| NW corner of Ave 53 & Van Buren; Sec. 12, T6, R8 | 8 | 3 HP; |
| NW of Dillon and Ave. 46 (W of Tyler); Sec. 20, T5S, R8E | 77 | 20 HP, 8/93 |
| SW corner of Ave. 49 & Hwy 86; Sec. 31, T5S, R8E | 16 | 1.5 HP, 7/93 |

## Prior studies using values for static well water levels.

The TWG had access to two reports which estimated the average static well water depths from the ground surface in the lower Coachella Valley.

A report by Boyle (1993) estimated two average static depths, 120 feet for the area not receiving gravity supplies from the Colorado River, and 100 feet for the area receiving gravity supplies.

A report by JMLord, Inc. (1993) estimated an average static depth of 175 feet. In an unpublished report to CVWD, the groundwater engineering firm of O'Neill and Fogg later revised this estimate to 116 feet.

The TWG does not have access to the detailed data used in these reports.

## Estimated depths to static well water levels.

The results from Tables 2, 3, and 4 were plotted on a map of the CVWD distribution system. Contour lines of depths to static water levels in wells from the ground surface were then approximated. The result can be seen in Figure 1. The contour lines are approximate, but they do provide a general sense of the magnitude of the values.

Figure 1. Contours of depth to static well levels. 1992-93. Depths are in feet from the ground surface.
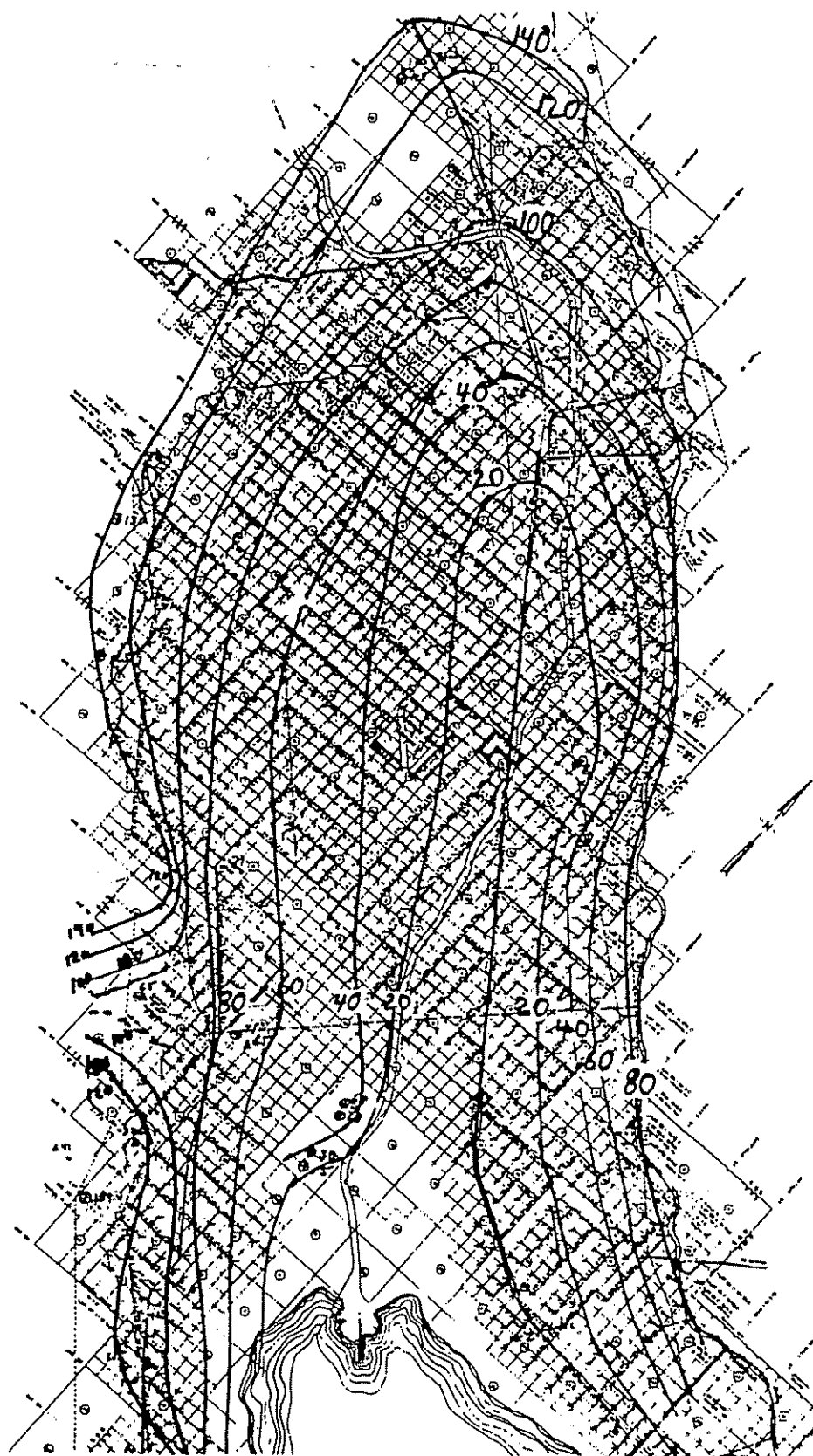
## Non-Agricultural Pumping South of Point Happy

**Coachella Valley WD**. CVWD maintains its own wells for municipal and other purposes, which are generally non-agricultural. The exact volumes of pumping have not been provided.

**City of Indio**. The City of Indio maintains its own wells for municipal uses. The engineering department of the City of Indio provided several pages of pump data. Those are summarized in Table 5.

Table 5. Acre-Feet (AF) pumped from wells in the City of Indio. 1990-92.

|      | J   | F   | M   | A    | M    | J    | J    | A    | S    | O    | N   | D   |
|------|-----|-----|-----|------|------|------|------|------|------|------|-----|-----|
| 1990 | 619 | 729 | 968 | 1101 | 1344 | 871  | 1606 | 1457 | 1281 | 1077 | 983 | 810 |
| 1991 | 725 | 762 | 712 | 972  | 1196 | 1344 | 1403 | 1412 | 1157 | 1173 | 972 | 743 |
| 1992 | 766 | 648 | 732 | 1019 | 1269 | 1346 | 1555 | 1478 | 1277 | 1169 | 990 | 753 |

Annual totals:       1990: 12,846 AF
                       1991: 13,002
                       1992: 12,570

## Surface Discharges into the Salton Sea

**Valley Sanitary District**. The Valley Sanitary District receives the sewage from the City of Indio, plus from some minor surrounding areas.

Valley Sanitary District (VSD) discharges water into the White River Storm Channel. Table 6 shows data provided by VSD. The difference between influent and discharge is probably that which is used to irrigate pasture at the treatment plant. The values are provided on the following page.

In summary, about **35% of the pumped water** from Indio is discharged directly back into the White Water Storm Channel.

Table 6. Flow data for Valley Sanitary District, Indio, CA. Values in Millions of Gallons (1 million gallons = 3.685 AF)

| | Influent | | | | | | Combined Discharge | | | | | | Activated Sludge Plant Discharge | | | | | | Pond Discharge | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | '88 | '89 | '90 | '91 | '92 | '93 | '88 | '89 | '90 | '91 | '92 | '93 | '88 | '89 | '90 | '91 | '92 | '93 | '88 | '89 | '90 | '91 | '92 | '93 |
| Jan | 102 | 105 | 136 | 140 | 137 | 137 | 92 | 98 | 117 | 117 | 133 | 140 | 77 | 72 | 102 | 90 | 100 | 110 | 18 | 24 | 15 | 27 | 32 | 30 |
| Feb | 102 | 101 | 123 | 126 | 131 | 131 | 92 | 78 | 100 | 100 | 118 | 122 | 84 | 61 | 100 | 79 | 92 | 106 | 11 | 17 | 3 | 21 | 26 | 16 |
| Mar | 103 | 129 | 138 | 139 | 133 | 137 | 82 | 92 | 97 | 116 | 108 | 97 | 82 | 83 | 97 | 91 | 78 | 97 | 0 | 11 | 0 | 25 | 30 | 0 |
| Apr | 109 | 130 | 138 | 137 | 134 | 139 | 72 | 76 | 104 | 91 | 128 | 97 | 71 | 73 | 93 | 85 | 91 | 97 | 7 | 3 | 14 | 6 | 37 | 0 |
| May | 124 | 135 | 146 | 136 | 145 | 141 | 78 | 93 | 78 | 89 | 78 | 71 | 78 | 79 | 95 | 89 | 78 | 71 | 0 | 13 | 0 | 0 | 0 | 0 |
| Jun | 129 | 132 | 154 | 132 | 146 | 143 | 73 | 109 | 90 | 76 | 77 | 78 | 77 | 87 | 99 | 76 | 77 | 78 | 0 | 2 | 0 | 0 | 0 | 0 |
| Jul | 138 | 136 | 162 | 152 | 144 | 144 | 59 | 77 | 68 | 88 | 77 | 80 | 84 | 74 | 96 | 88 | 77 | 80 | 0 | 0 | 0 | 0 | 0 | 0 |
| Aug | 126 | 132 | 156 | 142 | 147 | 152 | 59 | 90 | 94 | 87 | 80 | 91 | 77 | 90 | 97 | 87 | 80 | 90 | 1 | 0 | 0 | 0 | 0 | |
| Sep | 118 | 124 | 156 | 142 | 143 | | 68 | 86 | 87 | 92 | 74 | | 73 | 92 | 98 | 92 | 74 | | 0 | 0 | 0 | 0 | 0 | |
| Oct | 117 | 130 | 148 | 132 | 141 | | 73 | 108 | 112 | 99 | 96 | | 73 | 98 | 99 | 97 | 91 | | 12 | 11 | 13 | 2 | 5 | |
| Nov | 104 | 129 | 135 | 130 | 133 | | 91 | 131 | 118 | 97 | 118 | | 68 | 97 | 100 | 97 | 106 | | 24 | 34 | 18 | 0 | 12 | |
| Dec | 117 | 139 | 135 | 137 | 131 | | 99 | 123 | 106 | 130 | 124 | | 82 | 97 | 91 | 105 | 106 | | 18 | 26 | 17 | 25 | 18 | |
| ** | 3.8 | 4.2 | 4.7 | 4.5 | 4.5 | | 2.6 | 3.2 | 3.2 | 3.2 | 3.3 | | 2.5 | 2.7 | 3.2 | 2.9 | 2.9 | | 0.2 | 0.4 | 0.2 | 0.3 | 0.4 | |

** Annual daily averages

## Aquitard Leakage/Recharge

There is little information regarding this subject. Tim Taylor of the Riverside Country Environmental Health Dept. (79733 Country Club, ph 619-863-7000) made the following points about groundwater conditions.

- Synthetic or volatile organics (ie, nematicides) have shown up in the deep groundwater at the edges of the aquitard. However, none have appeared in the municipal wells which are in the area of the aquitard.

- His office has a tremendous amount of information regarding water quality from wells, but it isn't organized. In order to organize it one would need to correlate the water quality information with well log data. One problem is that on many of the older wells, the logs are unavailable.

- One edge of the aquitard is between Jefferson and Washington, west of downtown Indio. In that area there are very high levels (about 160 ppm) of nitrates in one well. He mentioned levels of about 60 ppm in other nearby wells.

- Although well standards were published in 1981, only within the past 3 years has new well construction been monitored. Now a 200' seal is required on all new wells in the aquitard area.

- For the old wells, there were two philosophies regarding upper seals:
  i) Don't put in any seals, and get a larger capacity because water comes from both the upper and lower aquifers. These wells had gravel packs to the ground surface.
  ii) Put in a seal, because the upper aquifer has poor water quality. Some of the old wells had gravel packs only to within 200' of the surface, and then the space above that was filled with the remaining driller's mud.

- Although there are water quality tests done on municipal wells, he is unaware of such tests done on agricultural wells.

- CVWD publishes a map showing the zone of the valley with a water table at less than 10 feet below the ground surface. Most people believe that the aquitard boundaries exist about a mile or so outside of that 10' boundary.

- If the TDS of well water is less than 200 ppm, the well is very deep and is effectively shielded from the water above the aquifer.

- If the TDS is greater than 200 ppm, there is mixing of the two layers, probably through the well itself.

# References

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